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Technology Acceptance for Hearing Aids: An Analysis of Adoption and Innovation

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Abstract:

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The interactions between patient and health care professional can be improved with patient-centered care and smarter consultations. The user should be monitored during their trial period and consultations should be based on need instead of scheduling. Online tele-audiology will remain a potential alternative to in-person clinic visits.

The emerging over-the-counter hearing aids will likely become an accessible alternative to true hearing aids once available. Personal sound amplification products and consumer electronics are adopting hearing aid technology to varies degrees and these lines will become more blurred as technology marches on.

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Abbreviations

CI. Cochlear Implant

HA. Hearing Aid

HCP. Health Care Professional. (Usually referred to audiologists or other professionals for measuring, dispensing or fitting HAs).

OTC. Over-the-counter. (OTC hearing aids can be bought from stores without a HCP).

PSAP. Personal Sound Amplification Device. (An unregulated device that is not an HA, but offers similar sound amplification).

Abstract

Hearing aids remain under-adopted andunderused despite advances in technology. The major adoption barrier is people being denial that hearing aids are necessary, while the price and social stigma are the top reasons why they may not get one after accepting their need. The price depends on each country's healthcare policies, while the stigma is associated with the hearing aid size. Hearing implants do not have the same stigma as they are more personal to the user.

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consumer electronics are adopting hearing aid technology to varies degrees and these lines will become more blurred as technology marches on.

1. Introduction

Hearing loss is one of the most common forms of chronic physical disabilities, only behind arthritis and heart disease (Victory, 2021), affecting over half a billion people in the world. Age-relating hearing loss affects more than 30% of adults over the age of 50 years, and 70% of those over 70 (Hampson, 2012; Goman & Lin, 2018). It can also affect younger people: 15% of children in the United States having some degree of hearing aids, and hearing loss or tinnitus is the most common disability among US veterans (Victory, 2021).

It can be difficult to define hearing loss since different countries or states define it differently. The World Health Organization defines severe hearing loss as 61-80 dB in the better ear, and profound hearing loss as 81 dB or above in the better ear. There are three types of hearing loss:

- **Sensorineural** is the cause of 90% of hearing loss a (Rahmen, 2016). It is hearing loss in the inner ear or higher up in the brain function, and typically affects the cochlea directly. It is most commonly caused by ageing (McCormack & Fortnum, 2013). Patients with sensorineural hearing loss has several deficits in hearing and some sounds are not heard at all. Amplification will make speech loud enough, but with poor comprehension; resulting in the common complaint of the patient hearing but not understanding speech (Kim & Barrs, 2006)).
- **Conductive** hearing loss in the outer- or middle ear. Can be caused by blockage, as well as accidents, birth defects, disease or others. It can be treated through surgical or medical methods (Rahmen, 16). Conductive loss requires only simple amplification to increase loudness (Kim & Barrs, 2006).
- **Mixed** hearing loss is a combination of the other two.

Hearing loss cannot be corrected in the same way that vision problems can be corrected with glasses. Even advanced technology can only partially corrected for volume, distortion and other complex conditions. Furthermore, the ability to hear can be distinguished between **audibility** (to hear a sound) and **intelligibility** (to process and

understand what you hear) (Lescia, 2018). According to Beck (2019) "Hearing is perceiving sound, whereas "listening" is the ability to assign meaning to sound."

Consequences of hearing loss

Besides poor communication, hearing loss can have severe consequences to both the mental and social health of the patient. Adults with hearing loss often suffer from isolation and often withdraw from society or family (Wilson). Couples are also challenged when one of them has hearing loss. People may even try to hide their hearing loss because of stigma of ageing and low intelligence. Adults with hearing loss in high-income countries are twice as likely to be unemployed and earn half the median income of others.
Hearing loss is also one of the leading causes of dementia (Goman & Lin, 2018). The lack of engaged listening and communication can increase the risk of Alzheimer's or dementia by 2x, 3x and 5x times for mild, moderate and severe hearing loss. (Wilson).

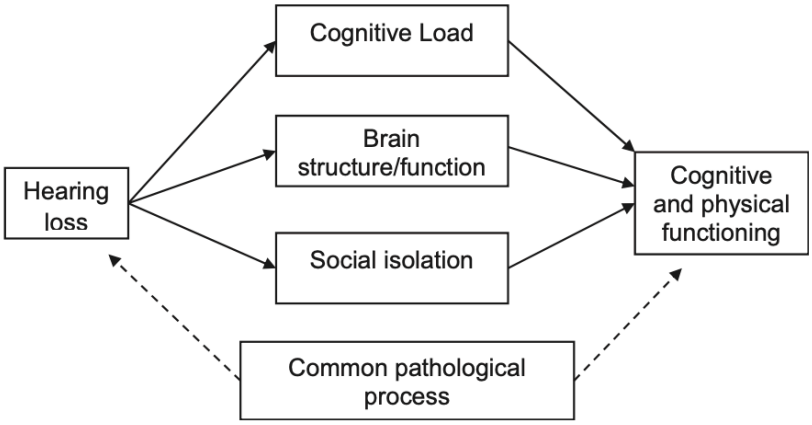


Fig. 1. The relations between hearing loss and cognitive and physical functions. (Solid lines represent mechanic pathways, and dashed lines represent underlying common factors). (Goman & Lin, 2018)

Oticon has identified five different brain problems from bad sound to the brain:
1) increased listening effort, 2) increased mental load, 3) reorganised brain functionality, 4) accelerated cognitive decline, and 5) accelerated brain volume shrinkage.
Furthermore, these problems can turn into three general life problems: 1) social isolation and depression, 2) dementia and Alzheimer's disease and 3) poor balance and fall-related injuries.

Hearing aids

Hearing aids (HAs) are the most universal and practical way to counter hearing loss. An HA is essentially a device to amplify sound (Hampson, 2012), and is described by the United States Food and Drug Administration (FDA) as "any wearable sound amplifying device that is intended to compensate for impaired hearing" (Clark & Swanepoel). They have existed since the 17th century in various incarnations, such as acoustic ear trumpets, eventually become small enough to wear on the ear with the invention of the transistor, and have now moved into digital and finally wireless (Rehman, 2016). The most significant change was the introduction of digital signal processing (DSP) in 1996 and programmable DSP in 1999 opened up for innovations like feedback cancellation and noise reduction (Kim & Barrs, 2006; Edwards, 2020). Today, older analogue HAs have effectively been replaced by digital hearing aids which also offer better control of the sound manipulation and the possibility of personalised settings and features (Hampson, 2012).

For patients with severe hearing loss, HAs may not be sufficient. They may instead require implanted hearing aids which are surgically inserted in the skin or skull. Implants come with different medical risks, but can drastically improve the hearing of those patients.

Adoption and barriers

About one-third of people with hearing loss wear hearing aids, and this number has been increasing yearly (Victory, 2021). As the technologies and device quality have improved, satisfaction with hearing aids has increased to an all-time high 83% over the last two decades (Signia, 2019; Victory, 2021).

However, despite the advances, hearing aids remain underused (Hampton, 2012; Victory, 2021). Less than half of those with hearing loss have seen a healthcare provider in 5 years (Victory, 2021), and people often wait up to 10 years after experiencing hearing loss to seek professional help (Barnett et al., 2017; Bluestein & Weinstein, 2016). Only 14% of those with mild hearing loss gets HAs, although this increases to 37% and 58% for moderate and severe hearing loss, respectively. (Carr, 2020). Furthermore, there is a problem with users not using wearing their HAs despite evidence of positive correlation between time wearing them and benefits of doing so (C.K, 2017).

There are many reasons why people with hearing loss don't seek out help to purchase HAs, or keep them in the drawer, including cost, stigma, inconvenience, attitude, or other health problems (Barnett et al., 2017). 1.2 million patients in the US are candidates for the alternative cochlear implantations, but only 5% get them. Furthermore, up to one-third of HAs are rarely or never used. A trend that increases with age (Hampson, 2012).
Richard Einhorn (2017) points out that "the adoption rate for hearing aids has grown slowly despite extraordinary technological advances in the field."

Challenges and innovations

HAs have received many improvements in recent years, including comfort and connectivity, but have lacked behind on the primary function of speech perception (Lesica, 2018). The primary user complaint is the inability to understand speech in noise (Beck, 2019). Better hearing in noisy settings was the number one listening preference of 10,000+ users (Signia, 2019). Previously, the two key features to help this was directional microphone technology and digital noise reduction.

Lesica (2018) argues that "In recent years, most improvements have been limited to aesthetics, comfort, or secondary functions (e.g., wireless connectivity). With respect to their primary function - improving speech perception - the performance of hearing aids has remained largely unchanged."

In the real world, listeners must "locate, identify, attend to, and switch attention between signals so as to maintain communicative competence and a sense of connection with their surroundings" (Groth, 2020).

In addition to normal hearing aids, the market has had a number of Personal Sound Amplification Products (PSAPs) which are not true hearing aids, but offer the basic feature of sound amplification. Furthermore, the United States have accepted, but delayed, the sale of over-the-counter (OTC) HAs which can be dispensed without an authorised audiologist or other health care professional (HCP).

With consumer electronics, like Apple's AirPods, utilising HA features like noise cancellation, the lines between what is or is not a true HA is becoming blurred.

Finally, hearing implants are an option for those who have severe hearing loss and may not benefit from a normal HA. Hearing implants have some unique HCP and user factors which will be discussed.

1.1. Research questions

The aim of this thesis is to describe and analyse the user adoption factors, the patient and health care professional interactions, and the relevant future technologies and innovations affecting these. The primary research question is:

How do technological innovations and adoption factors predict the future of hearing aid instruments and user care?

This will be supported by the following supporting questions:

What are the primary drivers and barriers for user adoption?

What are the emerging technologies and innovations that improves adoption and user care?

What are the adoption factors and innovations for implantable hearing aids?

This thesis will answer these questions by finding the relevant adoption factors and innovation technologies in order to predict the necessary requirements for future HA industry. Chapter 2 will review the past literature on the topics, chapter 3 will explain the theoretical framework, while chapter 4 will explain the methodological methodological approach. Chapter 5 will describe the technolocal basics of hearing aids and review the current manufacturers and products, and chapter 6 will summarise the most essential takeaways from expert interviews. Chapter 7 will analyse the data through the perspective of the UTAUT model and predict the future innovations. Finally, chapter 8 and 9 will discuss and conclude the previous content.

2. Literature review

In order to gain a fundamental understanding of the HA technology, adoption factors and general market tendencies, as well as how hearing implants apply to these, a number of academic papers and journals were reviewed. This chapter will describe the main takeaways from the most relevant literature.

2.1. Technology Adoption literature

Chen et al. (2018) examined why HA adoption remains low despite hearing loss being a major disability all around the world. They review several technological adoption theories and discuses their applications for HI adoption from the elderly, including TBP, TAM, UTAUT-1 and 2, STAM, SDT, and TRA. They hypothesise that attitude, subjective norm, and trust in E-health products and audiologists positively influence their intention to adopt an HI.

Convery et al. (2011) examines if self-fitting hearing aids can overcome barriers such as device cost, distrust of professionals and lack of knowledge. While patients may find it difficult to assemble and fit their own HIs, similar produces have proven advantageous in other fields. The majority of participants endorsed the concept of self-fitting HAs and thought that they would gain personal benefits, including the ability to self-adjust their device and not being necessitated to visit the clinic. Some still preferred professional guidance.

Barnett et al. (2017) systematically reviewed the literature on motivators, barriers, and compliance factors for patient access and utilisation of HIs. They found that the primary motivators in seeking hearing help is severe hearing loss, time spent with it, and difficulty understanding speech in background noise or television. Other reasons were HCP and family communication as well as self-efface. The primary barriers were denial, finances, stigma, inconvenience, other health problems or unrealistic expectations. Four compliance factors correlated positively with HA use: positive support from partner, higher hearing loss handicap, positive attitude towards help and high perceived self-efficacy.

Gunarathna C.K (2017) studied the patient perception of HA usage and reasons for non-compliance. Most participants used their HA most of the day and almost half were

strongly satisfied. The most common reasons for poor compliance were reduced clarity of HI, users' relatives demanding its use, background noise and ear mould problems. About two-thirds of participants were not aware of follow-ups and most had never been to one. The authors recommend the following steps: change of people's attitude, better patient education and communication, follow up appointments, and government/ organisational support.

Gallagher & Woodside (2018) looked at factors that affect HA adoption by analysing interviews from three groups of participants: regular users, irregular users, and non owners. All three groups reported similar benefits and challenges, although the degree of self-reported hearing loss severity was the main factor for HA adoption. Other key factors for adoption and use were age and length of time owning a HI. The major challenges reporter were lack of information and no scheduled follow-up appointments after HA adoption.

Goman & Lin (2018) summarised the epidemiolog research that has informed United States initiatives for hearing care. They find that despite two-thirds of old people suffering hearing loss, fewer than 15% of age 50+ use an HA. The reasons for this has been linked to four main factors, including a lack of awareness and understanding, the high cost of treatment and devices, as well as barriers to care access and technology. The authors predict that 'over-the-counter' HAs and other hearable devices can will have a substantial impact on innovation.

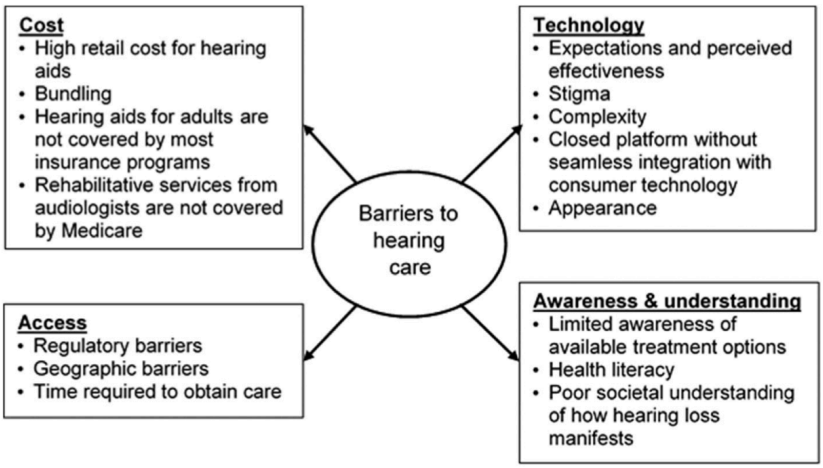


Fig 2. Four major groups for barriers to hearing care (Gom & Lin, 2018)

Ng et al. (2016) studied how innovations affected the experiences of patients and clinicians, focusing on smart phone connected hearing instruments. They found that clinicians appreciated the extra time they spent understanding the patients better, while patients felt frustration with Bluetooth connectivity. Patients often found that the phone connectivity "normalised" HIs and decreased the associated stigma. They conclude that this may be the key to make the HA a positive accessory rather than a burden.

Ritter et al. (2020) found that he primary reasons why people with hearing loss did not use their HAs included: (1) non-necessity, (2) stigmatization, (3) lack of integration into daily living, (4) unreadiness due to lack of education, (5) discomfort, (6) financial setback, (7) burden, (8) professional distrust, and (9) priority setting. They suggest that understanding these internal and external attributions for nonuse were necessary to increase HA use.

Abdellaoui & Tran Ba Huy (2013) found that hearing aids are generally favoured 6-9 months after starting use. 90% of users find their HA reliable, 87% found it well-adopted to their needs, 92% no longer felt disabled, and 73% used their HI all the time. However, it also found that many one-third of users did not follow up their HI prescription and that motivation and cost were limitations for setting and follow-up.

MarkeTrak is a series of HA consumer survey report. MarkeTrak VIII from 2008 (Kochkin, 2010) found the top ton satisfaction criteria to be: overall benefit, clarity of sound, value, natural sounding, reliability, sound richness/fidelity, use in noise, hearing in small groups, comfort with loud sounds, and sound of voice. The overall satisfaction rating had increased from 68% to 74% in four years while the ratings for dissatisfaction and non-use fell about 4% each.

MarkeTrak X found the primary non-adopter reasons for both those patients who have been recommended an HCP or who those have taken no steps; the primary barriers being non-need and expenses. It also compares HA owners to PSAP (Personal Sound Amplification Product), finding the top PSAP situations to be when talking or watching TV at home. The areas where people where comfortable with using over-the-counter (OTC) HAs were using features and maintaining, while they were not comfortable with selecting HA and troubleshooting.

2.2. Hearing implant literature

Lagerkvist et al. (2020) reviewed literature containing data from 1352 patients of the Ponto BAHS. They conclude that the Ponto system improved hearing ability with an average of 35 dB. While major complications are rare, skin reactions are common. 98% of patients found that their quality of life was improved after the Ponto surgery.

Pittman confirmed previous results that children with hearing loss benefit more from an abutment implant than a magnet or softband. 17 children would complete four tasks (word recognition, word repetition, rapid word learning and nonsense-word detection) with a bone conduction device coupled to an abutment. The results showed a small benefits of word recognition, and improvements in identification, repetition and acquisition of new words. Children with the poorest performance with a softband had the highest improvement with the abutment.

Christensen et al. compared functional gain at 500-4000 Hz for children who could at first not get traditional bone-conduction devices, then moved to Baha (Bone-anchored hearing aids) with softband and then unilateral Baha implants. The study sample included 10 children (6 months to 16 years) with bilateral conductive hearing loss.

The study found a statistically significant improvement with the Baha Softband over traditional bone-conduction HI. An implanted Baha has as much gain as a bone-conduction transducer at all frequencies. It concludes that the Baha system, via Softband or implant, should be used over traditional bone-conduction HIs.

Osborne et al. (2020) evaluated the clinical outcomes of the Oticon wide implant in 47 children in the UK. They found positive results for skin complications and revision surgery rates compared to other studies.

3. Theoretical Framework

The following chapter will lay out a theoretical framework by describing and assessing a number of theories regarding user adoption and behavior. The primary theory, UTAUT2,

will have the most detailed description, since many of its constructs have a similar construct in other theories.

3.1. Theoretical model overview

A number of adoption and innovation theories were considered. Before discussing the main theory, UTAUT2, other theories be discussed briefly. Some of them provide the inspiration and essential constructs for UTAUT2.

Diffusion of Innovation

The Diffusion of Innovation ("DOI" or "IDT") theory was developed by Everett Rogers in 1962 and is one of the oldest social science theories . The purpose of the theory is to explain how ideas or products are spread, or diffused, through a society or people - specifically how people choose to "adopt" the ideas by changing their habits. The theory states that potential adopters will own a product at different times, depending on their preferences and attitude towards innovations.

It categorises adopters into five groups: *Innovators* are the first to own new innovations, *early adopters* adopt innovations after being made aware of them, *early majority* need some evidence that innovations work before adopting them, the *late majority* are skeptical and waits for others to adopt successfully, and finally *laggards* are conservative and wait before being convinced or pressured to adopt.

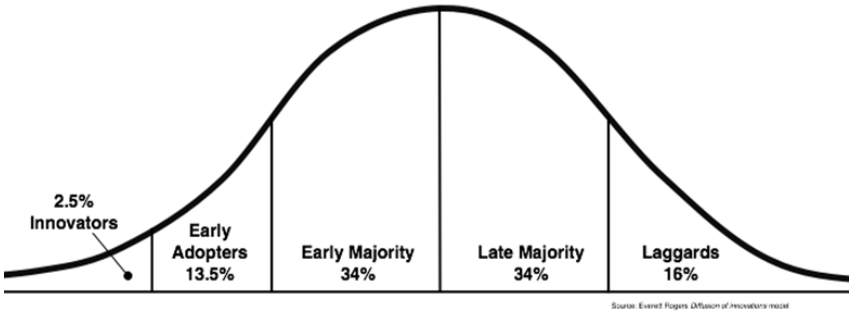


Fig 3. Adoption distribution curve for the five groups. (LaMorte, 2019).

In addition to the five adoption groups, the theory has a number of stages of adoption:

Awareness of needs of innovation (1), decision to adopt (or reject) innovation (2), *initial use* to test it (3), and *continual use* in the future (4).

These steps are influenced by five major factors:

- *Relative advantage*: how the innovation is seen as an improvement over the thing it replaces.

  - *Compatibility*: how it integrates with the current habits and needs of adopters. For technological integration, this can be seen as double concern: both the users' habits of living as well as setting up smart devices that works with the current electronics of the house.
- *Complexity*: how easy it is to use and control the innovation.
- *Triability*: the option to try out an innovation before fully adopting it.
- *Observability*: seeing the tangible results provided by the innovation.

Ultimately, IDT is one of the oldest theories which laid the groundwork for future theories by presenting both the adoption groups, adoption stages and adoption factors.

Theory of Reasoned Action (TRA)

The Theory of Planned Behavior (TRA) from 1975 is based on social psychology and has been used to explain individuals' behavioral intention (Venkatesh et al. 2003). It assumes behavioral intention is driven by *attitude*, a person's feeling about performing an action, and *subjective norm*, a person's perception of how other people will influence their actions. TRA has been used in different cases of social psychology, technology acceptance and health care. This includes an Italian study which found that trust between audiology and patients can increase the adoption of HIs (Chang et al.).

Theory of Planned Behaviour (TBP)

The Theory of Planned Behavior (TPB) is an extension of TRA from 1991 for predicting a persons intent to engage in specific behaviours at certain times. The main component, behaviour intent, is influenced by the attitude about the likelihood of the behavior having a positive outcome and the evaluated risks and benefits (LaMorte). It is composed of six constructs that represent's a persons' control over their behavior: attitude,

behavioral intention, subjective norms, social norms, perceived power, and perceived behavioral control.

Technology Acceptance Model (TAM)

The Technology Acceptance Model (TAM) from 1989 was designed to predict information technology acceptance in a job context (Venkatesh et al. 2003). It excludes Attitude, and instead uses Perceived Usefulness (how a system would enhance job performance) and Perceived Ease of Use. TAM2 from 2000 looks at three time points in the implementation, and adds Subjective Norm. TAM3 from 2008 adds individual differences, system characteristics, social influence and facilitation conditions which determines the TAM2 construct (Lai, 2017).

Motivational Model (MM)

The Motivational Model applies Extrinsic Motivation, the perception that performing an activity will result in a positive outcome, and Intrinsic Motivation, the perception that performing an activity is worth it in itself (Venkatesh et al. 2003).

Senior Technology Acceptance Model (STAM)

The Senior Technology Acceptance Model (STAM) came from combining TAM and UTAUT2 to determine technology acceptance among older adults in Hong Kong (Chen and Chan, 2011). The model includes the factors like gerontechnology, self-efface, anxiety, facilitating relationships, self-reported health conditions, cognitive ability, social relationships, attitude to life and satisfaction and physical functioning.

Self-Determination Theory (SDT)

Self-Determination Theory (SDT) combines two types of psychological motivations: extrinsic, which is doing something for a purpose, and intrinsic, which is doing something for the sake of its own enjoyment. It uses the constructs competence, autonomy and relatedness for psychological needs.

SDT is normally used for consumer behaviour when shopping online, and may not be ideal to predict adoption of HIs from mostly elderly people.

3.2. UTAUT2

The Unified Theory of Acceptance and Use of Technology (UTAUT) was developed by Venkatesh et al. in 2003 (and updated in 2012), and is used for explaining user intentions and behavior. It proposes three direct determinants of intention to use (performance expectancy, effort expectancy and social influence) and two direct determinants of usage behaviour (intention and facilitating conditions). Additionally, the impacts of experience, gender and age are factored as moderators for the constructs.

Performance Expectancy

Performance Expectancy is defined as the degree to which a person believes that using a solution will help improve their performance. The similar constructs from other models are *perceived usefulness* (TAM/TAM2), *extrinsic motivation* (MM) and *relative advantage* (IDT) (Venkatesh et al., 2003). Performance expectancy is the strongest predictor of intention and important among all measurements, but age and gender may also have an impact (Venkatesh et al., 2003). The hypothesis by Venkatesh et al. is that the effect of performance expectancy changes with gender and age.

Effort Expectancy

Effort expectancy is defined as the degree of ease when using a system. The similar constructs from other models are perceived use (TAM/TAM2) and ease of use (IDT) (Venkatesh et al. 2003, p. 450). Effort expectancy may be more important for people with increasing age which makes it harder for people to process complex software systems that they are not used to. Venkatesh et al. hypothesises that the influence of effort expectancy on behavioural intention depends on *gender*, *age* and *experience*.

Social Influence

Social influence defined as the degree to which a person believes that other people wants them to use a system. Social influence is represented as subjective norm in TRA and TAM2, and image in IDT (Venkatesh et al., 2003, p. 451). Social influence may decline with experience, but become stronger with age.

Venatesh et al. hypothesises that the influence of social influence on behavioural intention depends on *gender*, *age*, *voluntariness* and *experience*, with the effect being strongest for older women, with limited experience in mandatory settings.

Facilitating Conditions

Facilitating conditions is defined as the degree to which a person believes that there is an organisational or technological structure to support the use of the system. The other models represents it with *perceived behavioural control* (TPB) and *compatibility* (IDT) (Venkatesh et al., 2003).

It is expected that if a model does not include effort expectancy (like TPB), then facilitating conditions become predictive of intention, whereas it will not be in models with both constructs (Venkatesh et al., 2003, p. 454). Older workers tend to appreciate help on the job, especially with complex IT systems.

Venkatesh et al. hypothesises that facilitating conditions will not have a large influence on behavioural intention, and that the effect depends on *age*, *gender* and *experience*.

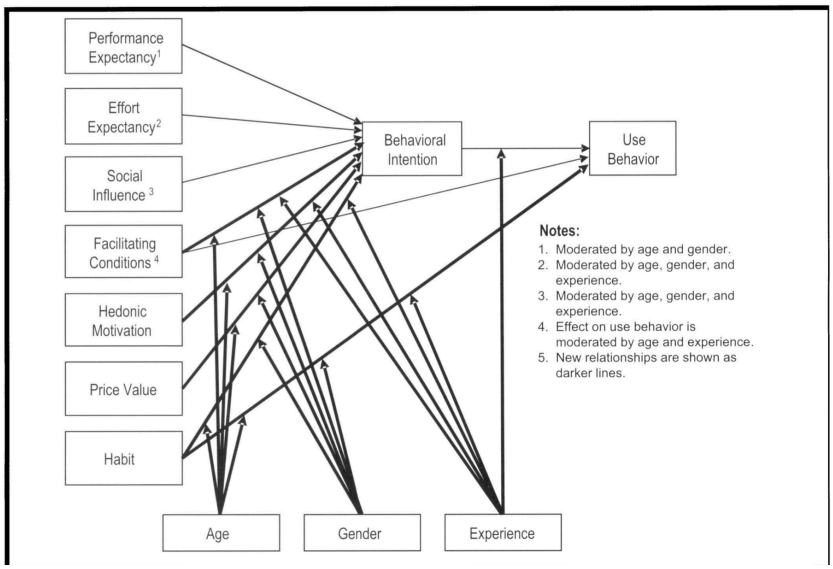


Fig 4. UTAUT2 Research Model, showing relations between each construct and its effect on Behavioral Intention and User Behaviuor, as well as its moderators (Venkatesh et al. 2012)

Excluded constructs and behavioural intention

Compute self-efficacy, compute anxiety and attitude have been factored in other models, but are not included as direct determinants in UTAUT, as they are hypothesised to not have a large impact on behavioural intention. Based on the theory for all the intention models, Venkatesh et al. hypothesises that *behavioural intention* will have a large and positive impact on *usage*.

3.2.1. UTAUT2 additions

While the original UTAUT model was primarily meant to be used within *organisational contexts*, such as employee technology acceptance, the updated model in 2012 was meant to address the *consumer use context* (Venkatesh et al., 2021, p. 158). This was arguably necessary in the last decades' growth of consumer electronics and increased adoptions of advanced technological devices in normal households. The new model presents the new content by identifying three key constructs, changing some of the previous relationships in the old model, and introducing new relationships (Venkatesh et al. 2012). The three key contrusts are:

Hedonic Motivation

Hedonic Motivation is defined as a "fun factor", the enjoyment or pleasure the user gets from using the technology. This has shown to be a determinant, which is perhaps evident from the way modern technology is often being branded as user friendly and entertaining. Venkatesh et al. hypothesises that age, gender and experience will impact the effect of hedonic motivation.

Price Value

Price Value is defined as the impact of the cost of a technology or device. An important difference between the old organisational context and new user content is that the cost

of technology is switched from the company to the consumer. This means that a positive price value is shown as a determinant. Venkatesh et al. hypothesises that age and gender will moderate the price value on behavioural intention, so that it will be strongest for older people.

Experience and Habit

Experience is defined as a person's opportunity to use a technology depending on different time points after their first use. Habit is defined as the degree to which people tend to perform automatic learned behaviours. Habit is seen as prior behavior and is measured as the degree to which a person believes their behavior to be automatic (Venkatesh et al. 2012). Venkatesh et al. (2012) hypothesises that age, gender, and experience will impact the effect of habit on both behavioural intention and technology use, with the effect being strongest for older people who are experienced with the technology.

3.3. Reflections on theories

Most of the discussed theories are relatively old and have been used in many contexts of technology adoption. Each theory cannot be seen as standalone, as the theories borrow from each other and use similar constructs.

The theory which will be applied in the analysis is UTAUT2. It is one of the newer theories which was developed in 2003 and updated in 2012, and many of its constructs are borrowed and built-upon from other models. The main weakness of the original UTAUT from a consumer-market perspective is that it was designed for a professional work environment and does not consider the price value; but this construct was added in UTAUT2, making it viable for a consumer perspective. UTAUT2 also has a qualitative focus, whereas some other models are more quantitative, making it more ideal for a user-focused analysis (especially in regards to the patient-centered focus will be discussed later). The constructs of UTAUT2 will be discussed in relation to research data in the analysis chapter.

4. Methodology

This chapter will describe the methodological approach of the project, including research aims, types of research, and data gathering and processing strategies.

The research data consisted of a combination of *primary* and *secondary* data. The primary data came from personal expert interviews, and the secondary data came from previous second-hand research, including white papers, academic papers, surveys and other publications.
The data was a both qualitative and quantitative, with a greater focus on qualitative data. I have found data with statistical models, but the majority of data was mostly qualitative. Additionally, most of this data was *descriptive*, identifying the characteristics and scope of the research problem.

Search strategy

There were two overall search strategies for finding data from previous research papers. The first one was to search for key words in various search engine. The second one was to follow the relevant references in those papers, thereby directly following a series of related literature.

The chosen search engines included both general and research specific sites, including Google Scholar. AAU library, IEEXXX, ResearchGate, ScienceDirect, and PubMed.gov. The chosen search terms included: ‘Hearing loss’, ‘Hearing aids’, ‘hearing instruments’, ‘Hearing aids future’, ‘hearing implants’ and ‘Hearing aids technology”.

Articles were included based on the following criteria:

- The study mentioned adoption factors, or explained technologies.
- The study was published between 2000-2021.
- Both qualitative and quantitative data were included.

4.1. Interviews

In addition to second-hand literature, the other primary data gathering method was experts interviews. The next section will describe the interview theory framework, preparation and technique.

Interview theory

The first-hand research was done through qualitative interviews. The qualitative interview is way to access the opinions, experiences and activities of the subjects (Brinkmann & Kvale, 2019).

Brinkmann and Kvale presents the two metaphors as the interviewer as a 'miner' (knowledge collector) who seeks out existing data separated from the later data analysis, or the 'traveler' (knowledge producer) for whom interviewing and analysis are intertwined knowledge. Arguably, my interview methods were most close to the miner interpretation, although some interviews had parts of traveler conception as well (for example, when a question or comment lead to a more exchange of ideas instead of a one-way information).

The interviews can furthermore be seen as a research instrument to get reliable reports rather than a social practice where participants give accounts based on situations (Brinkmann & Kvale, 2019).

Finding participants

The interview participants were found either directly or indirectly through my assistants position at Oticon in Smørum, Denmark. I arranged the interview with Jes Olsen, the president of Oticon Medical, after having participated in his mandatory introduction course about the department.

The interview with Hans Henrik Phillipsen (Ida Institute) and Thor Højlund Olsen (Oticon Discovery) were both arranged after a colleague had mentioned that their respective fields could be relevant for my research. The interview with Shari Ebert was arranged after I had seen a link to her blog post on the company Sharepoint homepage.

In addition to the four primary interviewees, I talked to two Oticon marketing employees that a colleague had reached out to. These dialogues were a loosely

structured interview/conversation hybrid and were not recorded. They will not be mentioned specifically, but have been used for inspiration and verification of the topics.

Interview structure

Brinkmann and Kvale (2019) states that "a qualitative interview is usually semi-structured; it has a sequence of themes to be covered, as well as some prepared questions. Yet at the same time there is openness to changes of sequence and question forms…" The interview were planned as combination of *structured* and *unstructured* question and answers. I tried to have four types of questions in mind: introductory questions, transition questions, key questions and closing questions (Castillo-Montoya, 2016).

Specific questions were planned, but with room for the interviewee and interviewer to organically discuss related topics outside of the pre-made questions. The interviews with Hans Henrik Phillipsen and Shari Ebert were the only one in which the questions were sent beforehand (since both of them were involved with the topic of patient-entered care, the questions were almost identical). Both of these had the interviewer go through each question, and then I would follow-up with a few extra questions based on their responses or relevant topics.

The other interviews were following various degrees of pre-planned questions and spontaneous discussion. The interview with Jes Olsen followed a few primary questions with long responses, while other interviews were more in the form of a free-flowing dialogue with more spontaneous questions.
For example, prior to the interview with Thor Højlund Olsen I did to have access to specific information about what the Discovery department was working with, and consequently the first question was regarding the basic purpose of Discovery.

Interview analysis

Interviews are often framed as inductive, deductive, or adductive, depending on the way they are being analysed (Brinkman and Kvale, 2019). My approach was mostly inductive because I followed a 'systematic examination of similarities within and across cases to develop concepts, ideas, or theories' (Brinkman and Kvale, 2019). In contrast, the

deductive approach typically seeks to falsify hypothesis, while the adductive makes generalisations between various outcomes.

The interview data was compared against both the other interviews and the literature. Since only two of the interviews (Ebert and Phillipsen) had the same topic and question formula, it was not possible to do a direct one-to-one comparison between the interviewees answers, but instead of looking for similar topics and agreements/ disagreements across the interviews.

4.2. Delimitations

The topic of implantable hearing devices were meant as a side topic to complement the bigger questions. The thesis contain descriptions and comparisons between different types of implants, but not the specific medicinal products. The topic was limited to a basic description of the technologies and medical procedures and did not explore the advanced aspects and difference between market solutions. The interview with Jes Olsen (of Oticon Medical) was accordingly mostly focused on the user aspect, and only mentioned detailed descriptions of the technology or medical procedures that were relevant from this perspective.

The thesis is focused on user behaviour and technology which are issues not dependent on worldwide localisation and countries. Some parts mention statistics within the United States, including the opinion of audiologists and market share of HA manufacturers. The US was focused because these numbers were most easily available in research papers. It stands to reason that the numbers in Europe are similar or at least not drastically different; regardless, it is no the focus of the thesis.

5. Technology and Products

5.1. Hearing Aid fundamentals

A hearing aid consist of four essential parts (Grewal & Irwin, 2012; Rahmen et al., 2016):

- a microphone, which pick up sounds and converts it to electric signals.
- an amplifier, which amplifies the signals and sends them to the receiver.
- a speaker, which converts the sound to an acoustic wave familiar to the ear.
- a battery, which powers all the components.

The microphone picks up environmental sounds and voice, and converts them into electrical signals that can be amplified by the receiver, which is a small speaker that plays the amplified sound into the user's ear. It has a small dome which is a plastic/ silicone attachment that fits inside the ear.

Fig 5. Example of a BTE Hearing Aid (Hampson, 2012).

Most HIs run on disposable zinc batteries which typically last for 6 to 10 days (Johnson, 2017). Rechargeable batteries is a more environmentally friendly and more convenient solution. Traditional rechargeable batteries used nickel-metal-hybride (NIHM) which last for about half a day after being fully charged and need replacing once a year. The newest innovation is **lithium-ion** batteries which last up to 24 hours and is replaced every 3-4 years (Johnson, 2017).

Hearing aids used to be analogue, but are now almost exclusively digital (C.K, 2017). An *analogue* HI amplify the speech and noise signals equally, and some of them can use a microchip for different listening settings by pressing a push-button (Rahen, 2016). Analogue HI are less expensive than digital HA, but the lack of modern features have made them obsolete. *Digital HAs* converts sound waves into binary codes and produce the same signals at the output (Rahen, 2016). Digital hearing offers better flexibility and

typically comes with built-in features such as bluetooth, directional microphones, noise reduction, Telecoil, frequency lowering and Direct Audio Input (DAI).

Hearing Aids styles

A hearing loss patient will have to decide between several types of hearing aids, including monaraul or binaural, size and style, and circuitry and options (Kim & Barrs, 2006). Hearing aids can be divided into two major styles/categories: Behind the-ear (BTE) and In-the-ear (ITE), each with their own sub categories.

Fig 6. Types of HAs (Rehman et al., 2016).

'Behind-the-ear' (BTE) HAs sits behind the user's ear. The receiver (speaker system) is inside the main body and attaches a thin cord to the ear canal. They come in different shapes and sizes and have strong processing power. They are the most common type of HAs, and are suited for mild to severe hearing loss (Hampson, 2012). BTEs are the most common type of HAs with 87% of the United States market share (Strom, 2021) and higher consumer satisfaction than custom HAs (Groth, 2020).

'Receiver-in-ear' (RIE) (also known as RITE or RIC) is a sub-category of BTE where the receiver sits inside the ear (instead of the device). One of the advantages is that microphone placement within the ear canal can drastically reduce wind noise (Groth, 2020). RIE is the most popular BTE-type, accounting for about 79% of all sold HAs in the US (Strom, 2021).

'In-the-ear' (ITE) HAs fit inside the user's ear and are semi-visible to almost invisible. They are best suited for mild to moderate hearing loss. These tend to be less common and common in different types: *Invisible-In-the-Canal (IIC)* where HA is hidden in the ear canal. *Completely-In-the-Canal (CIC)* where the HA is hard to see, but not fully hidden, and *In-The-Canal (ITC)* where the HA sits in the ear canal with a faceplate visible. The tradeback of being smaller and discreet is that they tend to have shorter battery lives, fewer features and less amplification range due to feedback issues from microphone and receiver placement (Hampson, 2012).

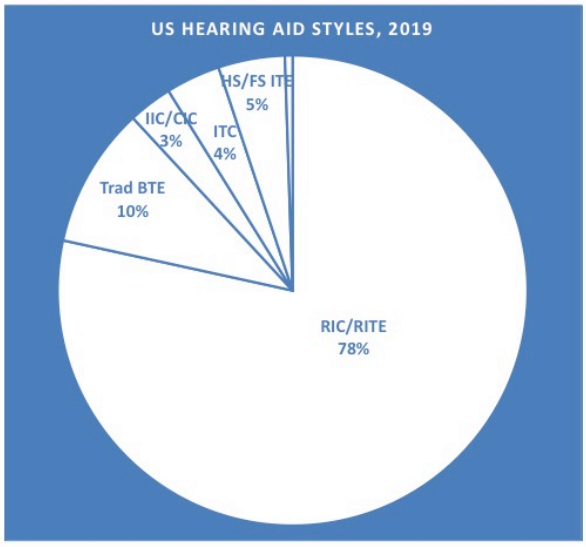


Fig 7. Popularity of HA styles in the United States in 2019 (Strom, 2020)

Hearing Aid Features

Sound quality

As innovation progressed, HAs have moved from the simple task of amplifying sound to address other issues and offer advanced services.
The invention of *directional microphones* may be the biggest advance for hearing in noise (Kim & Barrs, 2006). They are helpful when speech signal comes from the front and the background noise come from other directions (Hoppe & Hesse, 2017). Adaptive directional microphones only activate when they recognise a speech signal from the front. *Wind noise elimination* and *'own voice processing'* have addressed issues of sound quality. And since the majority of people with tinnitus also have hearing loss, some HAs have tinnitus programs to provide relief.

In addition to sound quality, the connectivity features have also been improved. It used to be common to only use one HI for one ear, but the ability to couple two hearing aids (*binaural coupling*) is relatively recent. At first, any change of parameter settings (such as increasing the volume) would affect both HIs, but now individual change is possible. Binaural coupling can scan 360 degrees around the user to identify sounds and reduce background noise (Johnsson, 2017).

Direct transmission

Besides amplifying sound, there are a number of ways for any HA to receive sound directly, which can be useful for social event like classrooms or churches.

Induction loops work by having an electrical current flowing through a wire that induces a magnetic field around it. This allows for minimal background noise by directly transmitting the speech from the speaker's lips to the listener's ear (Kim & Barrs, 2006).

A *Telecoil (T-Coil)* is used to detect the magnetic field in a small like (e.g. telephone receiver), transmitting the sound directly to the HI instead of the user hearing it through the air via the HI. This is one method of receiving phone calls, although not all modern phones has the required electromagnetic power. T-coils can also be used for to receive induction loops integrated in the floor (Hoppe & Hesse, 2017), for hearing inside

buildings like churches and theatres.

Frequency Modulation (FM) systems have the speaker wear a transmitter that sends radio frequency signals to receiver worn by the patient (usually attached to the HI). This method requires a hard wire.

MF allows wireless transmission at better quality and longer distances compared to a T-coil (Hoppe & Hesse, 2017). Since they are expensive and inconvenient, they are best used for specific situations where hearing is important (such as classroom lectures).

Device connectivity

Practically all modern HIs have Bluetooth connection which allows them to connect to phones (either directly or via an app), accessory devices, or other devices. While HAs normally require an application to connect via Bluetooth to smart phones, modern phones are starting to be directly compatible. **Made-for-iPhone** (MFI) allows direct pairing in the iPhone's "Accessibility" settings, while Android-phones have **ASHA (Audio Streaming for Hearing Aids)** that lets HI connect and play direct audio like any other Bluetooth audio device. Certain modern HA can also connect to other Bluetooth connected devices, including door bells, smoke alarms and baby-phones (Hoppe & Hesse, 2017).

5.2. Hearing Implants

Hearing aids are the easiest and safest solution to hearing loss, but may not be adequate solutions for patients with middle-ear disorders, near deafness or other impairment (Tisch, 2017); they may require surgically inserted hearing implants. Implantable HAs can be divided into partially and fully implantable systems. The partial systems have parts of the HA implanted, while fully implanted systems contain all components (Tisch, 2017).

	Partially implantable	Fully implantable
Advantages	Simple battery change or upgrade to new technical components	Cosmetically “invisible”
Disadvantages	Visible components	Battery change is only possible by surgery. Body sound problems with microphones under the skin.

-Figure 8. Advantages and disadvantages of partial- and fully implanted HA systems (Tisch, 2017).

5.2.1. Bone-conduction implants

Bone-conduction implants (BCD) can be categorised into two groups: **Direct-drive BCD** which transmit vibrations directly to the skull bone, and **skin-drive BCDs** which transmit vibrations through the skin.

Direct-drive BCDs are divided into *active transcutaneous BCDs*, where the transducer is implanted under intact skin, so the vibrations are sent directly to the skull bone, and *percutaneous BCDs*, which are usually BAHA (Reinfeldt et al., 2015)
Skin-drive BCDs can be *conventional* where the device is usually attached with a softband, or they can be *passive transcutaneous* which use an implanted magnet.
A third type, **In-the-mouth BCDs**, are neither direct-drive or skin-drive. The vibrations are transmitted from a piezoelectric transducer through the teeth to the skull bone (Reinfeldt et al., 2015).

BAHA (Bone Conduction Hearing Aid)

The BAHA was the first direct-drive BCD (Reinfeldt et al., 2015). Bone anchored hearing systems (BAHA) use the user’s natural ability to transfer sound through bone conduction through a transcranial simulation of the cochlear (Barr & Kim). It is the most common form of hearing implant, and an option for patients (children and adults) with conductive hearing loss or single-sided deafness who suffer from mild-to-moderate hearing loss (Reinfeldt et al., 2015). BAHA is manufactured by Oticon and Cochlear Baha in Sweden (the original inventor).

The system consists of two parts: 1) a small titanium implant in the bone behind the ear and 2) a sound processors attached to the implant. The sound processor converts sounds into vibrations and sends them through the skull bone and into the inner ear.

BAHS are arranged by their location of transducer (percutaneous and transcutaneous) and type of coupling to the temporal bone (direct and indirect) (Pittman, 2019). Transcutaneous devices indirectly stimulate the temporal bone through a softband or magnet, the signal passing through the skin. Percutaneous devices directly stimulate the temporal bone via an implanted transducer/abutment. This bypasses signal reduction through skin layers, but can cause skin irritation (especially for children, although the risk is low).

BAHA has been seen as given greatest benefit to those with single-sided deafness, although it is missing directional hearing. The surgery procedure is simple and low risk, and the operation does not restrict the patient from active outdoor activities; however, there may be skin complications (Reinfeldt et al., 2015).

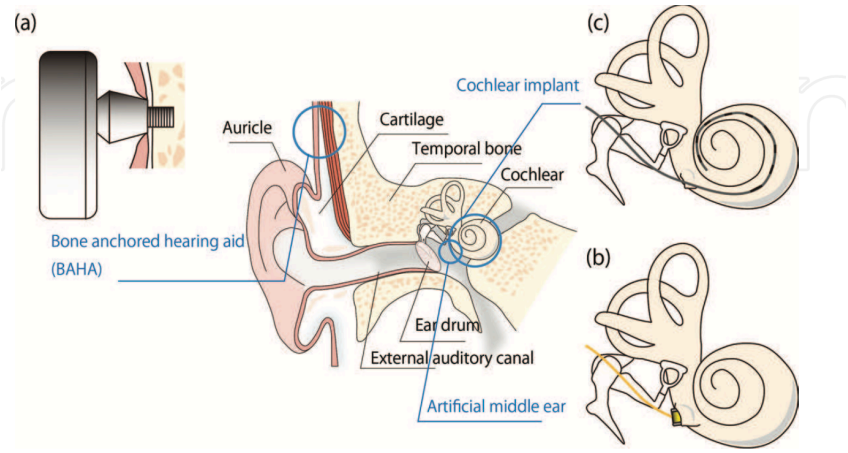


Fig 9. Overview of implanted hearing devices (Shimokura, 2018).

5.2.3. Cochlear Implants

Cochlear implants are used to treat patients with severe-to-profound sensory-neural hearing loss (Pisoni et al., 2017). They usually uses electrical impulses to directly stimulate the auditory nerve though the cochlea (Johnsson, 2017), allowing the brain to interpret the signals.

Cochlear devices have a transmitter, receiver, microphone and processor and electrode array (Rehman, 2016). The external speech processor is worn over the user's ear, which

picks up environmental sounds and sends as electronic signals to an electrode array, implanted into the cochlea (Johnsson, 2017).

Hybrid cochlear implants (half cochlear implant, half hearing aid) is an option for those whose hearing loss is too severe for normal HIs, but too mild for cochlear implants. They use a cochlear implant for the user's damaged mid/high frequency hearing, and an HI for the low frequency hearing (Johnson, 2017).

Cochlear implants is not a cure for deafness, and require practice therapy after surgery, but they can help patients comprehend sounds and speech that would otherwise be inaudible. Speech reception and sound localisation are some of the gaps between CI and normal hearing (Johnson, 2017).
The effectiveness of cochlear implants have been recognised by medical experts and been described as "the most succesful neural prosthesis developed to date" (Johnson, 2017). (Pisoni et al., 2017).

5.3. Hearing aid manufacturers and products

This chapter will describe the newest and most relevant hearing aid models from the world's biggest hearing aid companies. The factor that will be looked at include technological features, health related features.

5.3.1. Oticon

Oticon was founded in 1904 by Hans Demant, who bought an American hearing aid for his wife who had hearing loss. His son William Demant took over after his death in 1910. The parent company name was changed to William Demant Holding A/S (and just Demant in 2019) to separate the group and the business. Oticon has branches in multiple countries, mainly Denmark and Poland.

Oticon lost market share in the late 1980s due to poor reactions to changing market conditions (Bailey, A. 2020c). The then CEO, Lars Kolind, implemented a new organisational and managerial structure known as the "spaghetti organisation". This new approach was project-focused, did away with vertical hierarchies and a more free office

structure. While it was later softened, it remained an influence on the company going forward. In 2008, the economic crisis and intensified competition further challenge Oticon.

Demant now focuses on multiple business, including hearing aids (like Oticon, Bernafon, Sonic Innovation, Neurelec and Oticon Medical. They also have diagnostic instruments, personal communication and instrument dealers.

Oticon Technologies and Innovations

Oticon technologies include *OpenSound Optimizer*, an innovation that analyzes listening environments and adjusts amplification levels accordingly., *Speech Rescue LX* that increases comprehension by shifting frequencies levels, and *Spatial Sound LX* , a NearField Binaural Communication tool for faster binaural processing, better spacesound and helping the brain orient and localise sound. *BrainHearing* is the newest major innovation for improving listening effort, speed understanding and memory. It aims to reduce mental processing power to better process speech in the brain.

Oticon Hearing Aids

Oticon More is the 2020 flagship model that claims to give the brain the full perspective. It is powered by the *Polaris* platform built with Deep Neural Networking and trained with 12 million real-time sound scenes. This aims to provide better sound in different environments. It also features ASHA (Audio Streaming for Hearing Aid) that lets Android phones stream directly (similar to MFI for iPhones). It features MoreSound Intelligence which is claimed to increase speech understanding by 60% and improve the full sound scene by 60% (Rosenblum, 2021).

Oticon Opn (2016) runs on the Velox Platform and process data 50 times faster than its predecessor, “Inium Sense”. Opn is the first Oticon HI with MFI - Made For iPhone. This means it can connect to the phone and stream audio without any intermediary devices. Opn also claims to be the world’s first internet-connected HI. It connects to the Internet via IFTTT (If This Then That), a web service which enables control of the home via IoT (Internet of Things).

Oticon Opn S (2019), an upgrade of OPN, is based on the Velox S platform, which further. improves speech understanding, listening effort and memory recall. New technologies include BrainHearing, Speech Rescue LX and OpenSound Optimizer. Opn S comes with either Rechargeable lithium-ion batteries or replaceable 312 batteries and an optional Telecoil.

5.3.2. Starkey

The only American-owned hearing technology company, Starkey was founded by Bill Austin in 1967 and is currently located in Minnesota. It has over 5000 employees in 28 facilities operating in more than 100 countries (Bailey, 2021).

Starkey Technologies and Innovations

Starkey has been one of the first brands to offer almost invisible in-the-canal (ITC) HAs as well as technologies like MFI streaming (Bailey, 2021). Their *IQ sound processing* system improves speech in noise.

The *Thrive Hearing App* focuses on health and fitness. It combines Body Score (physical activity) and Brain Score (HI use and engagement) to get a Thrive Wellness Score that gives a snapshot of the user health. It also has features like Find My Phone, Translate, Transscribe, Self Check and remote hearing care. The new feature, Mask Mode, helps users hear people who are wearing face masks.

Starkey Hearing Aids

Starkey Livio Edge AI (2020) is one the first ever HI to use AI technology to track the user's body and brain health. It also features direct iPhone/Android streaming, accelerometers, transcription, translation and fall detection
Live Edge AI won the CES 2021 Innovation Award, selected by the Consumer Technology Association, for the accessibility category. Starkey'sChief Technology Officer, Achin Bhowmik, explained that it was chosen for its ability to understand and adopt to challenging listening situations, which was especially helpful during the Covid-19 pandemic. Its Edge Mode technology has also been effective at ensuring speech

intelligibility when wearing a face mask. The HA has also been named the best HA for 'overall health' and 'active lifestyles' by audiologists and consumer advocates.

Starkey Halo iQ from 2017 features Made-for-iPhone and sound processing, noise reduction and directional microphones. It also had geotagged GPS memories which informs the HA to automatically switch programs when arriving at certain locations (e.g 'work or 'home) (Bailey, 2021).

5.3.3. Phonak

Phonak is the largest hearing aid brand in the world (Bailey, 2020b). It is part of Sonova Holding AG (previously called Phonak Holding AG) was founded in Switzerland in 1947. It owns the brands Phonak, Unitron, Hansaton, Advanced Bionics and AudioNova Group. In 2013, it held 24% of the global HI market share and in 2018 it had 14,000 employees and active in more than 90 countries.

Phonak Technology and Innovations

The *SWORD wireless chip* enables binaural streaming and phone calls with less power consumption and better battery than previous chips. The *PRISM chip* doubles the memory and enables up to eight paired devices and two active Bluetooth connections (Bailey, 2020b).
AutoSense OS 4.0 was made to reduce listening effort and increase speech intelligibility. It features Speech Enhancer (up to 10 dB gain) and Dynamic Noise Cancellation (DNC). In a study of three scenarios, OS 4.0 was preferred over previous version.

Phonak Hearing Aids

Phonak Audéo Paradise (2020) is built on the PRISM chip and offers Dynamic Noise Cancelation, voice assistant with an ear tap, Bluetooth connection and app remote control. It comes with both rechargeable and replaceable batteries. Audiologist Michelle Brady named Paradise as the best overall HI in 2020.

Phonak Audéo Marvel (2018) is their previous main model which claims to be the world's first HI to fully support binaural direct streaming from most phones, including Androids which accounts for 86% of the market (Bailey, 2020b). Previously, only iPhones had access to direct streaming (MFI). Marvel won a CES 2019 Award Honoree in the Accessibility category.

Phonak Audio B-R (2017) was the first HA with lithium-ion rechargeable batteries (Bailey, 2020b).

5.3.4. ReSound

ReSound is the flagship brand of **GN Hearing**, the world's fourth largest manufacturer of HAs located in Denmark. It is part of GN Group, founded as a telegraph company in 1869. It currently has more than 5,500 employees and is active in over 100 countries (Bailey, 2020a).

ReSound Technology and Innovations

ReSound was the first HA manufacturer to offer Made-for-iPhone (MFI) HAs, contributing to the evolution of changing them from amplification devices for patients to actual consumer products (Bailey, 2020a).

M&RIE (Microphone & Receiver-In-Ear) has a microphone placed in the ear in order to improve sound quality, localisation, and wind noise. It has the flexibility to switch microphone state depending on listening environment (e.g. quiet, noisy, windy).
A study by GN Hearing found that the natural sound from M&RIE was preferred over alternatives by 3 out of 5 normal-hearing listeners and 9 out of 10 hearing impaired listeners. Another test found the overall and spatial quality ratings for M&RIE to be twice the ones for pinna (outer ear) compensation - with very little variability for the M&RIE ratings) (Growth, 2020).

ReSound HAs have built-in *Tinnitus Sound Generator* (TSG) to hide buzzing noises. *ReSound Binaural Directionality* is an ear-to-ear technology that allows two HIs to function as a single unit.

The **ReSound Smart 3D** works with the latest HI models, while **ReSound Smart** app works with older ones (both iOS and Android). The apps can adjust volume (including bass/treble), tinnitus settings, HI-location, and battery use. The Smart 3D can also have HCP make remote adjustments to programs.

ReSound Hearing Aids

ReSound One (2020) is the current flagship which builds on the previous model and seems to be the end of the LiNX series that began MFI streaming in 2013 (Bailey, 2020a). It uses a *C6 Chip Platform* to provide twice the memory and 50% more processing power as its predecessor. It It introduces the M&RIE technology as well as "Ultra Focus", beam forming directionality. It also has wireless audio streaming from phones. The One models are all receiver-in-canal (RIC) and use both disposable batteries with Telecoil and rechargeable lithium-ion batteries without telecoil.

ReSound Linx Quattro from 2018 also provides audio streaming, and uses 'Smart Hearing' sound processing platform.
ReSound Enzo Q uses the same platform as Quattro and is designed for users with severe-to-profound hearing loss. It has Binaural Directionality III to help locate sound.

5.3.5 Widex

Widex A/S was founded in Denmark in 1956 by Tøpholm and Westermann. Widex introduced the first digital in-the-ear (ITE) HA in 1995 (based on Oticon's research model). In 2019, Widex merged with Sivantos (Singapore) to form WS Audiology which owns the brands Signia, Widex and others. It has over 10,000 employees and are present in more than 125 countries (Copithorne,. 2020b).

WS Audiology describes their market drivers as 1) an ageing population, 2) increased noise pollution, 3) increased penetration of HI users and 4) increased demand for HIs.
WS Audiology describes their market drivers as 1) an ageing population, 2) increased noise pollution, 3) increased penetration of HI users and 4) increased demand for HIs.

Widex Technologies and Innovations

PureSound with *ZeroDelay* reduces low frequency interference by reducing sound delay from 7-10 to 0.5 milliseconds to make the sound more natural and undistorted.
SoundSense Learn is a machine learning technology that evidently leads to greater listening comfort and sound quality. The phone app lets the user choose environment and listening goals, asking them to compare setting A and B. The HA learns this preference and improves the experience accordingly. Studies have shown this method to increase perceived sound quality and listening comfort (Balling et al., 2020).
Zen Fractal Technology offers tinnitus relief by generating 'fractal tones', while the accompanying app features sounds and counselling for relaxation and sleep.
Fluid Sound Analyzer uses *SoundClass Technology* to automatically analyse and categorise environments and set device settings accordingly, without the need for specific programs. It features more sound classes (e.g. Quiet, Transport) and parameters (e..g. noise reduction, directionality) (Balling et al., 2020).

Widex Hearing Aids

Widex MOMENT (2020) is the newest flagship. It uses SoundSense for AI learning, and promises a PureSound experience with ZeroDelay technology. Widex claims that the MOMENT mRIC HA has the smallest rechargeable lithium-ion on the market. MOMENT was chosen as an horned of the CES 2021 Innovation Awards Health & Welles's and Wearable Technologies categories for being the "first digital hearing aid to incorporate dual artificial intelligence engines to improve real-time listening". Audiologist Michelle Brady named MOMENT the best HI for tinnitus in 2020.

Widex EVOKE (2018) began the SoundSense AI technology, inspired by Widex's "Real-Life Hearing" philosophy. It uses SoundSense Technology, consisting of SoundSense Learn and SoundSense Adapt, learning from the user's lifestyle and adapting to it. It is unique for using fuel cells for battery. A study found that users trying EVOKE rated their experience "Satisfied" or "Very satisfied" significantly compared to their own HAs (Balling et al., 2020). Widex EVOKE was chosen as "best for tinnitus" by ConsumerAdvocate.org.

Widex BEYOND (2016) was their first Made-for-iPhone device. It is compatable with Widex's wireless devices and supports T-coil functionalities.

5.3.6. Signia

Signia HAs were manufactured under Siemens before the company was brought by Sivantos (Singapore) in 2015 and merged with Widex to form WS Audiology in 2019 (Copithorne, 2020).

Signia Technology and Innovations

Signia was a pioneer for both analog and digital HAs, as well as directional microphones, and was among the first to develop wireless ear-to-ear for binaural HAs in 2004 (Copithorne, 2020).

Signia Xperience claims to be the world's first combination of advanced acoustic sensors and built-in motion sensor. It is a sound processing platform built upon *YourSound* technology which is made to respond to the user's listening surroundings. It uses a new chip and consists of three primary features: *Acoustic-Motion Sensors* for understanding the user's dynamic landscape,*Dynamic Soundscape Processing* for natural sound and speech, and *Own Voice Processing (OVP)* for natural sound of own voice.

Signia was the first company to introduce a *Face Mask Mode* in their app in July 2020. This mode helps users understand nearby people wearing face masks. Face masks can reduce frequencies in the 2000-8000 Hz range by between 3 to 12 dB.

Signia Hearing Aids

SIgnia Styletto X (2020) is made to look different than most HAs with a sleep, flat design. It features Bluetooth, remote control, OVP, Dynamic Soundscape Processing (DSP), Acoustic-motion sensors, directional microphones, rechargeable batteries, and mobile- and Qi wireless charging.

Pure X (2019) comes in the *312 X* model with rechargeable batteries and T-Coil, or the *Charge&Go* , a RIC device with small rechargeable batteries. The Motion Charge&Go X deliver 24 hours battery per charge, while newer versions increases it to 30 or 61 hours (HHTM, 2021).

Signia Silk X (2020) is designed for discretion and one of the world's smallest hearing aids. It comes equipped with silicone Click Sleeves that click onto HIs and fit into the ear.

5.3.7. Reflections on manufacturers and products

Looking at the various state-of-the-art HA devices on the market, it is clear that it is a market where the differences are in the details. Most of the manufacturers have mastered the creation of advanced digital HAs with all essential functions like directional microphones, smartphone integration and direct streaming. Each of the producents are also proud to boast that they were the first in the world to introduce certain technological features. With the quick innovations on the market it may be difficult to verify these claims.

Nevertheless, the brands seem to have certain focuses and disctintions. Widex seems to focus on offering unique and advanced software features that improves the user quality of life, especially with the MOMENT's AI learning and the EVOKE's tinnitus relief programs. They also have a history of innovation, being the first innovator in several areas. Starkey have become innovated in the AI and active/health areas. Signia has focused on making unique designs and innovations like face mask mode. ReSound newest innovation is the M&RIE technology which aims to solve the problems of microphone quality.

Finally, Oticon and Phonak, the two biggest manufacturers, appear to be the most all-around quality manufacturers. Their HAs are simple in design. Instead of experimental design and features, they appear to focus on the best possible professional products (such as with Oticon's More, which looks and functions almost exactly like their previous generation, but has new Deep Neural Network technology).

As Phillipsen argued in his interview in the next chapter, since the manufacturers and products are not hugely different, the consumer choice may not only depend on their products alone, but also on external factors, such as service and HCP communications.

6. Expert Interviews

In addition to literature analysis, the primary research data comes from interviews with experts of various roles in the HA industry. This chapter will present a summary of the interviews that describe the primary arguments, information and takeways from the interviews. Each summary will be divided into subsections according to topics. The full interview transscriptions are available in the appendix.

6.1. Hans Henrik Phillipsen

Hans Henrik Phillipsen is the Chief Anthropologist at Ida Institute. Ida has been funded by Demant since 2008 and focuses on the patient communication and educating HCPs about their needs. The foundation uses 25-30 tools, including tele-audiology and applications for both patients and HCPs. Its mission is to raise awareness of patient-centered care (PCC), and they currently have around 20,000 members who work with audiologists worldwide.

Patient-centered care (PCC). The classic medicinal model is an "error detection device" where the patient goes to the doctor who finds the diagnosis and prescribes a treatment according to protocol. Ida focus on PCC where the decisions must be made in accordance with the HCP and the client/patient and reflect their perspective og preferences in an individually tailored treatment. Another aspect is holistic approach and the "bio-psychosocial " model which considers social factors. Ida has worked with leading audiologists to identify 6 elements of PCC: 1) understanding of individuel preferences, 2) understanding of showing empathy, 3) involving family and friends, 4) listening actively to the patient, 5) asking open-ended questions, and 6) reflecting. Research has found that PCC improves health and psychosocial status. It also pays off economically, with benefits for both HCP and patient, especially in regards to trust which is important to the patient. The six big HA manufacturers are not hugely different in device quality, so other factors like audiology relations are in play.

Drivers and barriers. Price is one of the major barriers in countries without government funding. Stigma is also relevant, but decreasing as devices get smaller and smarter. Another factor is availability, with OTC (over-the-counter) HAs having both risk and potential depending on whether you think they hinder user contact or give them options.

HA fitting is also an important way to reduce non-use, and the IDA tools can help identify these issues.

Tele-audiology. Online consultations (teleaudiology/telehealth) are not necessarily for everyone, as both patients and audiologists are nervous about bad communication and loss of contact. Studies have shown that if the first session is in person, the following can be online. Geography is also a factor, especially for those living far from their clinic. Teleaudiology is a useful and important option, and some elements will remain after the Covid-19 is past. It requires that HAs can be remotely fitted, and many apps already offer this. Henrik is surprised that clinics do not have better contact to users during their first month trial period, surveilling their use and contacting them with feedback.

Technologies and features. Many patients have problem integrating their new HAs with the smartphone app, and this takes time away from proper learning. Bluetooth improvements are reducing the issue. A lot of users in their 70s are used to smart phone applications, but those in their 80s have bigger problems often. A potential future for patient-care is to use Artificial Reality to create a lifelike "avatar" of the audiologist who can answer the patient's questions (being worked on by Facebook Reality Labs). These must combine human PCC and technological elements to make them personal.

Device Merging. The industry is nervous about tech giants like Apple and Google entering the market, although the HA manufacturers are still far ahead. We are already seeing a 'merging' with HAs and consumer electronics. Apple's AirPods Pro have suppression of background noise, and Starkey's Livio HA is an example of an HA with body tracking, fall detection, transcription and more. People with hearing loss are becoming "consumers" of electronics. It is inevitable that "wearables" will become standard for people with mild hearing loss. Some of the features do not require hearing loss, such as going to a restaurant and having your device automatically switch sound settings.

Implants. Oticon Medical is a separate company and we are still talking about "patients" rather than "consumers". In order for implants to become an option for those with normal hearing, major innovations are required, especially to make up for the disadvantages. But they have amazing results if a child gets an implant before they are 1 year old. Hans Henrik Phillipsen met a deaf 6-year-old girl who could sing a song in tune after working on sound issues for half a year, suggesting that her hearing loss will not prevent her from living her life.

6.2. Shari Ebert

Shari Ebert has genetic hearing loss and is a hearing health advocate and owner of the blog Living With Hearing Loss. She is on the Board of Hearing Loss Association of America and author of the book "Person-centered Care from the Patient's Perspective."

PCC. Ebert argues that PCC gives good results because it marries the expertise of the audiologist with the expertise of the patient who knows their own situation best. PCC is the only is the only model that emphasises the patient's lifestyle and needs in order to recommend devices and activities.

Barriers. The primary drivers are stigma and price. HAs are still generally viewed negatively and associated with being old. The price can be a massive barrier in countries like the United States where the expense is not being covered.

Tele-audiology. Tele-audiology is a wonderful tool as long as it is captioned. It can be an issue with video lag, and some audiologists are bad with communication for personal consultations (like turning their back on the patient). It can also be difficult to do hearing measurements online or fit and clean devices. Captions help this, and tele-audiology is especially useful for those who live far from their clinic or do not have time. It likely will compliment, not replace, personal consultations.

Features. Connectivity technologies like Bluetooth and T-Coil are very important for connecting to other devices for things like calls and video. Noise cancelling is also important and HAs do not always do it well. Ebert visualise a future where you can point your phone at the person you are talking to and block out all other noise.

Innovations. People with hearing loss want solutions and they don't care what form they take. One societal and technological change is for everything to be captioned, such as video calls with a live transscript feature that doesn't require any special permissions, but also public presentations. It would also benefit normal hearing people who miss something. Society should acknowledge hearing's importance to overall health and consider this. Another issue is the simplicity of using HAs, including handling the small devices/batteries.

Merging. People are already using HAs for media and calls. Fitness features are also an option, but smart watches already do that. Consumer devices are going to start to be

used as HAs, more than the other way around, because the price point is different. People may use consumer devices for mild hearing loss and then eventually adopt a real HA if their loss increases. It will be an advantage if they are already familiar with similar devices. This may also help stigma by making devices trendy.

OTC. Over-the-counter HAs can advantage the consumer by increasing competition, innovation and bringing down prices. Easier access may also reduce stigma. For people with mild hearing loss, OTC devices can be situational tools that aren't used all day.

Implants. People with implants may be more emotionally attached because the implant greatly improved their hearing and became a part of their personality. There is less stigma because those with cochlear implant either are used to having it from childhood or gets it after longer periods with near deafness

6.3. Thor Højlund Olsen

Thor Højlund Olsen is the leader of Oticon's Discovery department which is a small team in R&D which looks at the future market products (3-4 years). They work at the crossroads of how to make emerging technologies relevant for the customers. Tools does not care if the new ideas or products start from a user requirement or new technology, as long it they go together. Discovery experiments with prototypes of both devices and applications that may or may not be functioning, and the solutions often come from multiple areas. They often work other innovationsteam like marketing and product management.

Drivers and barriers. There are big possibilities to help the many hearing impaired who still don't own an HA. Trols does not believe that price is a major factor. The recent developments focus on reducing the size of HAs, as well as other parameters including sound replication, connectivity features, personalisation and comfort. A big concern is the social influence of what potential user's hear from their friends. That is also why the size matters regardless of how good the design is.

Connectivity and features. Users often have an expectation that if their headset can do something, it should be possible for their HA as well. If they are used to stream music to their headset, they don't understand why their HA can't always do the same. This will be some of the expectations of future HAs. Connectivity-wise, Discovery is working to is making sure users can know if their HA is working as intended by making an app test.

Telehealth is another potential solution for online consultations. It needs to have a flexible model where the individual HCP and user can 'opt in and out' at different stages in the journey. One HCP said "I'll do anything to keep my clients happy and out of my clinic". But individual users may want to go to have their consultations online always, often, or not at all, so flexibility and personalisation is key. One HCP said "

Merging and signaling There is already a merging between HAs and consumer electronics since new HAs have features like direct streaming. There will likely be more PSAP (Personal Sound Amplification Products) with each their niche. It is a matter of branding and marketing. It may become for the user to differentiate products. This could help prevent stigma, but it depends on the situation. A product like AirPods Pro signals that you don't want to communicate while HAs signal that you do.

OTC HAs. Thor believes that if OTC HAs disadvantages the HA industry, it is because the companies failed to act the new market possibilities. The overall market will not be smaller, but it may become more complex. There is a risk that the consumers may be more confused by too many options.

6.4. Jes Olsen

Jes Olsen is the President of Oticon Medical, the department that handles cochlear implants (CI) and bone-anchored implants.

Clients and data. Olsen distinguishes two kinds of users/customers: the health care professionals (HCP) and the end users/patients. Medical's user demand data come from three primary sources: 1) how the company sees future innovations, 2) learning from the experiences with HA, and 3) exploring techniques from projects in cooperation with clinic advisory boards. Unlike the long history of HAs, implants have only been commercial for 20+ years and some technologies only for 10-15 years which means that some challenges have only been known recently. Data access is a major issue. Unlike the HA industry, which only deals directly with the clinic/dispenser who is then responsible for the user satisfaction, the CI industry is both wholesaler and retailer. The product is both expensive and regulated, making it difficult to get reimbursement. It is important to get a digital infrastructure where both clinic, manufacturer and user can access the data.

Clinics and connectivity. It is an issue that the clinics exists in a university-hospital environment because they are only used to short-term patients and not those who need new devices every 5 years. With an early growth of 20-30% new patients, a lot of resources are required to checkout patients without additional compensation. This requires the driver to more efficiency: more for less. An example of this is to change the patient care to be on-demand rather than on-schedule by 'surveilling' their devices and using test algorithms to call in patients in for checkup based on need instead of scheduling. Unlike HA clinics, which want the user contact, CI clinics prefer the user to do 'self-care' at home. Big Dat and AI can help the user inform the device/app about their preferences and secure user interactivity and responsibility.

The main user problems are solved by Bluetooth connection. Olsen assumes that half the patients use their implant to stream music and audio entertainment more than person-to-person communication. Many patients have never been able to use a telephone, and learning to do so requires practice. Another tool for self-care is communities where users support each other. Another example is that the surgeon will often test the implant by stimulating a nerve during the operation to see that both the implant and the nerve is working. An Oticon Medical representative is often present which is an extra expense which can potentially be avoided by having the implant measure data and send it to the cloud for easy access for the audiologist when fitting. The solution is a an IT system that ensure connectivity with different sources and is presented to the professional users who needs to see as much as possible.

Drivers and barriers. Olsen says that all CI users are past HA users too because of the risk of implants. Any hearing can disappear during operation and this can scare some patients. In regards to stigma, CI users often don't feel stigma because they see their device as part of their personality, whereas HA users see it as an accessory. However, there is still a social stigma though it is improving. It is a bigger problem for adults since kids in the Western world almost always get the CI early. There is a polarisation of the treatment system. Some believe in HAs and others in CIs. While the communication is getting better, the two sides have been seeing down on each other and counselled their patients not to get the other product.

Merging. An unsolved issue is that most CI users also use an HA. We must be better at integrating those two services. It is unclear if CIs becomes mainstream like HAs. If a patient can get by with HAs, they should, but CIs give a better outcome for people with severely profound hearing loss. Our limitations today is that the external part becomes too big. Many users only want an internal part that includes the entire device. Many

users are scarred off when told that their remaining hearing will disappear, and choose to wait several years hoping for technological improvements. The biggest group of patients who are not getting treatment are 70-75+ year olds with severely-to-profound hearing loss, and for CIs to become mainstream depend on making it natural for people to get one as they grow older. This becomes more normal, but will require a technological paradigm change.

6.5. Reflections on interviews

Phillipsen and Ebert share the same perspective that PCC is a necessary tool for improving the patient journey of being properly diagnosed and adopting an HA. J. Olsen also criticises the university hospitals for being good with short-term patients, but not lifelong implant users. After surgery, the goal is to keep patients out of the clinic by promoting selfcare and online support as much as possible.

The interviewees, with various degrees of skepticism, all saw tele-audiology as a useful tool that will compliment, not replace, in-person consultations, especially as remote fitting becomes an option.

T. Olsen mentioned an HCP who had said that he would “do anything to keep my clients happy and out of my clinic”. This is similar to how J. Olsen said that the Medical industry are trying to keep patients away after they get their implant. The difference may be that normal HA HCPs have different views on seeing their customers, while the implant industry in almost all cases want them to stay out.

Phillipsen and Ebert both pointed to price and stigma as two primary barriers for adoption. J. Olsen and T. Olsen agreed that the size of the HA or CI was a major factor for the stigma. Furthermore, J. Olsen and Ebert agreed that implants did not have the same stigma as HAs, primarily because their users saw their implants as part of their bodies and personality (especially if they got it from childhood).

The interviewes saw OTC devices as potential way to improve market competition and user choice, but with the downsides of confusion. The merger between HAs and consumer electronics has already happened or is about to. Ebert speculates that consumer electronics will borrow from the HA industry, and believes that some features, like fitness tracking, are better suited for other wearables (e.g. smart watches). T. Olsen

argues that a hearing wear signals the user's communication attitude, and it is unlikely that people will wear devices like AirPods when they want to communicate.

7. Analysis and Predictions

7.1. UTAUT2 Analysis

This chapter put the information gained from the research and described in the previous chapter into perspective through each of the UTAUT2 constructs.

It can be difficult to insert every aspect of HA adoption in a specific construct, so I will analyse within the construct that they fit the best and discuss how this applies.

7.1.1. Performance Expectancy

Performance Expectancy measures how much an individual believes using a system/ technology will improve their performance (at their job or in general). It is considered the most important adoption factor in UTAUT2, and it seems to be no different for HAs. Both sales and satisfaction has risen linearly in the last decade (Strom), suggesting that performance does correlate with adoption.

The consumer study MarkeTrak VIII determine the 10 most important factors for HA customer satisfaction. Most factors related to the quality with the top factors being "overall benefit" and "clarity of sound".

Historically, one of the primary reasons for non-adoption has been the patient believing that their hearing loss does not require an HA (Kochkin, 2012). There is a thin line between someone being in "denial" about their need for an HA or simply not being bothered by their mild hearing loss.

In regards to the non-use of HAs that are already owned and fitted, the primary reasons seem to be related to the above satisfaction actors: speech clarity, comfort, noise

difficulty, sound quality and overall poor benefit. Some users also find that there simple isn't enough situations where an HA is necessary. (McCormack & Fortnum, 2013).

In recent years, HAs have moved from a purely medical device designed for sound amplification to merging with consumer electronics. This means that the performance is not only measured in sound quality, but also other features, such as health or safety tools, like fall detection or fitness tracking.

7.1.2 Effort Expectancy

Effort Expectancy measures the degree of how easy it is to use a system/technology.

One of the common complaints about HAs is the difficulty with connection, an issue that may become smaller as Bluetooth technology advances. Another issue is the handling of the small devices which may especially be difficult for elderly users.

One study of HA adoption found that users find it difficult to operate their HA, remember to remove it before showering, or use in certain scenarios like at parties or talking on the phones (Gallahger & Woodside, 2018). Other issue are manual handling, battery change and volume control adjustments (McCormack & Fortnum, 2013).

Effort expectancy is specifically relevant for HAs because the average user is elderly. As HAs have become smaller, it may be more difficult for users with bad eyesight or hand coordination to handle them. As the Ebert interview pointed out, this is especially true for battery replacement (which typically has to be done every few days). The innovation of rechargable batteries may help with this since they only need to be placed in a charging station.

Smart phone integration is also a potential issue. Jes Olsen explained in his interview that users in their 70s or below are generally used to handling a smartphone, and can usually use it with their HA. However, those in their 80s may never have owned a smartphone and thus have a much harder time integration it with their device. Another potential issue is the need for smartphones and their apps to receive regular software updates (Kimball, 2018).

Effort expectancy may play a different roles in regards to OTC devices. On one hand, devices sold without an HTC may be less advanced and therefore simpler to use. On the other hand, lack of HTC support puts more responsibility on the user to figure out the device by themselves. The MarkeTrak 10 survey showed that most people are most comfortable with using and maintaining the hearing aid (Powers & Rogin, 2019), suggesting that Effort Expectancy is not a barrier for OTC HAs.

7.1.3. Social Influence

Social Influence measures how much an individual believes that important others think he should use a system/technology. Many people with hearing loss are influenced by the attitudes of their friends, family or significant others in regards to obtaining or wearing an HA (Ritter, 2020).

One of the primary barriers to HA adoption is stigmatization. It can be related to the concepts of 'alterations in self-perception, 'ageism' and 'vanity' (Ferguson et al. 2017), caused by the fear of looking old or disabled, and the misconception that only the elderly use HAs (Ritter, 2020). Stigma doesn't necessarily fit within the strict UTAUT2 definition of social influence as the individuel being influenced by "others believe he or she should use the system"; after all, it is possible that others may support their decision to use a HA, but the user still fear that there is a stigma from them. However, the corresponding construct "image", from the IDT theory, is more fitting as it defines image as "the degree to which use of an innovation is perceive to enhance one's image or status in one's social system" (Venkatesh et al. 2003). While image is usually positively influenced by the technology, this is a case where it may negatively affect it.

There is evidence that younger people are more concerned about stigma, with adults aged 45-44 being twice as likely to reject HA due to stigma than those aged 75-84 (McCornack & Fortnum, 2013). Ultimately, stigma has shown to a very inconsistent adoption factor in terms of predictability power, with some studies rating it highly and others lower. The innovations of smaller devices, better features and social acceptability has made the stigma smaller than it used to be.

In response to the stigma barrier, the general HA trend has become "smaller is better." The MarkeTrak VIII user study found that "the top influencing factor in this category is

convincing the individual customer that their HA is nearly invisible". This also correspond with Thor Højlund Olsen's interview statement that "size matters".

This leads to a trade-off between functionality and invisibility as ITE (in-the-ear) or IIC (invisible-in-the-ear) HAs usually aren't as powerful as the BTE (behind-the-ear) models. This may also be why BTE models are still dominating the market and ITE/ICE only has a small share. An alternative to smaller size is to focus on the design of the device, such as the case of Signia's Styletto X. Although Thor Olsen argued that no matter how many designs that are invented, size will always remain the main factor.

It is likely that design and visibility would be less important if the overall functionality and efficiency of HAs, especially in combination with smart phones, is advanced enough to make them fashionable (Einhorn, 2017; Wilson et al. 2017). For example, Apple's AirPods are often seen as a smart and fashionable status symbol, and a potential merging of consumer audio and hearing technologies may help this issue. Wireless connectivity solutions may also benefit normal hearing listeners in social situations such as classrooms or theaters (Einhorn, 2017).

There is less stigma for implants than for HAs. This may be because users see them as part of themselves and their personality, rather than an external device (J. Olsen interview). The stigma is smaller for children since children in the Western world)almost always gets the implant from early age and grows up with it.

7.1.4. Facilitating Conditions

Facilitating conditions measures how an organisational or technical infrastructure supports the technology use.

The HA market has two primary fascilitators: the HA manufacturer and the HCP (e.g. an audiologist or other hearing expert). Typically, the manufacturer will sell the HA through the HCP who is solely responsible for the counselling, hearing testing, sale and fitting of an HA.

One vital aspect of HCP support is the first month where the user tries a new HA (sometimes a trial). It is unfortunate that the HCP will often not communicate or check in with the user during this period (Phillipsen, 2021). One study found that seven out of

twelve patients were unsatisfied with that they had no follow-up appointment, and most found the service overall poor (Gallagher & Woodside, 2018). It would also be an advantage for the HCP to 'surveil' the user's HA activity in order to know if they are having any issues (Phillipsen, 2021).

Regarding HCP communication, technologies like tele-audiology has it possible to do consultations or fittings from home instead of at the clinic. This has made the process easier for people who live far away from the clinic or who would rather not go there (especially relevant for elderly people during the Covid-19 pandemic). On the other hand, tele-audiology can be technically difficult for some people. As Phillipsen said in his interview, it may help to have another person participating in the consultation.

In addition to the general user healthcare process, there are certain hearing technologies which require physical support. For example, induction loops system can be built within an auditorium or classroom with wire loops through the walls while the user wears a neckband to receive the audio (Kim & Barrs, 2006). On a smaller scale, technologies like T-Coils or Bluetooth can offer similar services. It is likely that upcoming advances in Bluetooth technology will replace the classic induction loops for easy access to public audio.

Regarding OTC HAs, the MarkeTrak 10 survey, which showed that potential users were comfortable with Effort Expectancy factors, also showed that they were concerned about assessing hearing loss, selection of HA and troubleshooting (Powers & Rosins, 2019). This suggest that Facilitating Conditions is a barrier for OTC devices.

For hearing implants, Jes Olsen explained in his interview that there is no separation between manufacturer and HCP. The implant company (for example, Oticon Medical or Cochlear) is responsible for both the manufacturing of devices as well as counselling, surgery operations and follow-ups of patients. The public healthcare system also serve serves as perhaps the most powerful facilitator; In most Western countries, almost all children are being screened for cochlear impairment at birth and often provided with an implant if necessary.

There is a conflict between the HCPs who believe in HAs or CIs. As explained in the Jes Olsen interview, each side in the discussion tends to look down on the other side and counsel their patients against the other product. It would benefit the patient if the HCPs

could counsel them objectively and explain the risks and benefits of both solutions.

7.1.5. Hedonic Motivation

HAs have been almost exclusively been applied a medical tool, designed to solve a patient's disorder. As such, there has been no real "fun factor" in buying and using them. However, with recent innovations and companion smart phone apps, they are moving from a medical devices into consumer electronics (as discussed with Phillipsen and Ebert). Hedonic motivation can be applied in two ways: the HAs themselves and the adoption- and fitting process.

One example is the "fitness" feature that comes modern HA apps, such as Oticon and Starkey. Some of these apps can track the time spent wearing the HA, encouraging them to wear it more often, but sometimes also provide more advanced features (such as with Starkey's Livio Edge AI).

Hedonic motivation may play an increasingly large role in the HCP interaction processes. In the class medical model, where the patient and HCP only focuses on fixing the defect/problem, leaving little room for enjoyable interactions. With approches like patient-centered care, there is a greater focus on the patients' perspectives, needs and feelings. These factors can make the process more enjoyable for the patient.

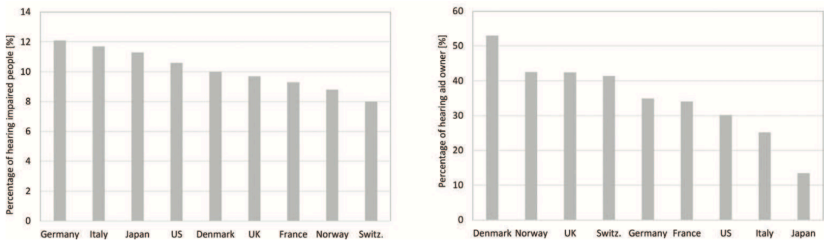
Tele-audiology is a potential way to make the fitting and support process more convenient. This process can become enjoyable by using technology. As an example of this to use AR to provide a virtual space with an audiologist avatar to interact with the user.

7.1.6. Price Value

Price value, or cost, is one of the few barrier factors that is highly dependent on localisation depending on whether HAs are paid for by government-funding in any given country. HAs can be expensive and one unit can costs between $2000 and $5000 ($2400 average) in the United States (Valente & Amlani, 2017; Grundfast & Liu, 2017). In Europe, provision varies between countries as some countries (Germany, France,

Belgium) health insurance companies provide HAs, but not always with full coverages, whereas Denmark, Finland and the UK provides them through the government health services (Hampson, 2012).

Hearing aid provision varies across Europe. In many countries (e.g. Germany, France, Belgium, Netherlands), health insurance companies are responsible for providing hearing aids but do not always cover the full costs of the devices. In Denmark, Finland and the United Kingdom hearing aids are dispensed by government National Health Services. The HA adoption is higher in countries with prescribed HAs, suggesting that price is a major factor. However, those who pay for their HA tend to be more satisfied, suggesting that the expense adds to its value (Shimokura, 2018).



Pic 10. Left: Number of people with hearing loss. Right: Number of people with HAs. The adoption is higher in countries with government prescribed HAs (Shimokura, 2018)

While Grundfast and Liu found that cost is the primary barrier, Valente & Amlani (2017) disagrees and points out that countries with government subsidised HAs do not have significantly higher adoption rates; for example, Norway (with no cost) only had a 42,5% adoption rate, while the US (with cost) had about 32% which was only estimated to increase by 10% if HAs were subsidized).

It would seem that the adoption rate for free HAs have increased throughout the years, as only 35% would get a free HA in 1978 compared to 56% in recent years (Kochkin, 2012). In addition to the price itself, another important factor is whether the HAs have money-back guarantee which is the number one product requests of potential adopters (Kochkin, 2012).

The insurance cost is complicated by the way that different American states have different insurance cost. For example, 2017 study found that California covered HIs if the pure tone hearing average (sensitivity between 500-4000 Hz) of the person's best-

hearing ear was above 25 dB HL (similar to the World Health Organisation's definition of 'slight hearing impairment') while for New York the same number was 30 dB (or 40 dB HL in both ears (Arnold et al., 2017). Similarly, there are differences in what aspects are covered, from device cost to rehabilitation.

The biggest potential innovation to drive down the price barrier may be OTC HAs. As they can be sold without going through an HCP, they are likely to be cheaper than regular HAs. *ADD*

7.1.7. Habit & Experience

Habit is an addition to UTAUT2 that has challenged the notion of behavioral intention as the main predictor of of technology use (Venkatesh et al, 2012).

Habit may play a huge role in the adoption of both HAs and accompanying samrt phone apps and accessory devices.

Phillipsen argued in his interview that it is not a major problem for users in their 70s to adopt smart phone connecvitivty with their hearing aids as they are likely familiar with smart phones to some extend. But users in their 80s often have more difficulty as they may never have used a smart phone before and possible be at an age where small screen icons and buttons are difficult to see or interact with.

7.2. Technology and Future Innovations

After the previous chapter described how HA adoption and technologies fit within the UTAUT2 model, this chapter will discuss these in greater detail and predict how they will influence the future of the industry.

Patient care

As described in Hans Henrik Phillipsen's interview, the old medical model saw the patient as having a defect that required. This issue was also brought up with regards to hearing implants by Jes Olsen who pointed that university hospitals are very good at handling immediate defects, but not at chronic, lifelong illnesses like hearing loss.

Tele-health, specifically tele-audiology, has forcibly become a necessary tool during the Covid-19 pandemic, especially since the prime users are elderly who are most at risk. In the future, it will remain a useful tool, but unlikely replace personal consultations. Some users may benefit from going to the clinic the first time, then having later consultations online (Philipsen interview), while others may go there every time, sometimes or do it purely online (J. Olsen interview).

Market

Hearing aid sales in the United States have increased linearly in the 11 years after the stock crash in 2008. Sales increased by 6,5% in 2019 (4.23 million sold) compared to 2018 (3.97 million, up 5,3% from 2017) (Strom, 2020). Naturally, this positive curve ended with the pandemic in 2020 where the market fell by 18% in the United States (Strom, 2021).

While there are reasons to believe that the hearing aid market has traditionally been resistant towards economic recessions, it is also uniquely vulnerable to a pandemic because their primary target consumers, elderly people, are less likely to leave their homes (REF).

While the hearing aid market has been partially resistant to the pandemic lockdowns, due to the medical necessity of keeping stores open and

The American chain Costco is an example of a wholesale store that has successfully integrated HAs. Their sales have grown about 20% early since 2011, accounting for an estimated 14% of all sales in 2019 (Strom, 2020), and are expected to make up 19% of all HAs sold in the US retail market by this year (Copithorne, 2021). Its main advantage is the convenience for customers to purchase HAs at a store they are used to visit for general purposes, while also using volume buying and distribution to sell them at lower prices than audiologists (Copithorne, 2021). The drawback are that they may not always have the newest products and there is a lower chance that the customer will have the test and fitting done by an experienced audiologist.

Over-the-counter hearing aids

Over-the-counter (OTC) HAs are a new category of HAs for adults with mild-to-medium hearing loss. Unlike regular HAs, which must be purchased through a HCP after consultation, OTC HAs can be purchased directly. They were expected to be approved by the FDA in the United States in 2020, but were delayed due to the Covid-19 pandemic.

The American Academy of Audiology has identified four primary reasons why OTC HAs may be necessary (Schmidt, 2021). First, the increasing price of HAs are not affordable for everyone; The average price in the United States is at $4,700 for a pair compared to $600-1000 for OTC models. Second, insurance is not always provided (especially not outside of Europe). Third, not everyone has access to a nearby audiologist. And four, many consumers demand more control of their purchases in an open market.

While OTC devices remain a debated issue, there are many positive possibilities, including market competition (Bluestein & Weinstein, 2016; Goman & Lin, 2016), consumer choice (Goman & Ling, 2016; Yong et al., 2019), stigma (Bluestein & Weinstein, 2016; Goman & Ling, 2016), prices (Bluestein & Weinstein, 2016; Goman & Ling, 2016) and innovation in design (Bluestein & Weinstein, 2016). Some evidence suggest that OTC-like HAs have similar performance to state-of-the-art HAs fitted by audiologists (Zeng, 2017).

However, there potential downsides such as safety concerns (Yong et al., 2019) and lack of guidance from an HCP. When asked about his opinion on OTC devices, Starkey President and CEO, Brandon Sawalich, demonstrated skepticism towards them, stating that "…the hearing healthcare professional plays the most important role in someone's hearing journey. By removing providers from the equation, I believe OTC hearing aids may confuse the consumer who is looking for better hearing. Patient satisfaction, which is at an all-time high, could plummet." (Sawalich, 2021). While his point is very valid, it is expected that he would be critical of direct competitors to Starkey's own business.

As mentioned in the Fascilitating Conditions section, potential users feel most comfortable with using, adjusting and maintaining an OTC device. This is likely especially true for those who already own an HA and is used to those tasks. Conversely, they feel uncomfortable with accessing hearing loss, selecting an HA and

troubleshooting. In other words, they are unsure about the tasks that normally require an HCP.

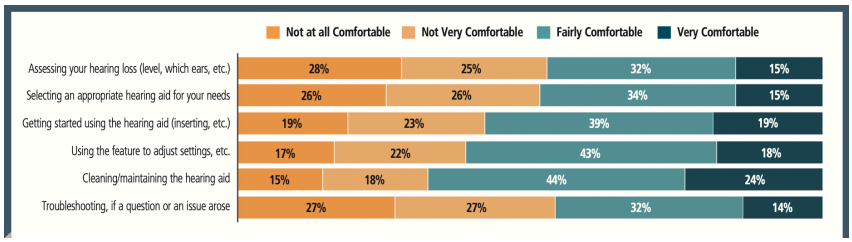


Fig 12. Comfort levels for OTC tasks by people with hearing problems (n=3113) (Powers & Rogin, 2019).

Machine Learning and AI

Artificial Intelligence (AI) and Machine Learning (ML) are two correlated technological tools that are increasingly used in many services and innovations, including hearing technology.

ML can arguably be used to enhance AI in HAs in two different ways: 1) by using ML to analyse data or sound from the lab, or 2) applying ML in real-time scenarios (Townend et al., 2020). The first method has usually been the only way to go, but the second one is becoming available in the newest HAs, such Oticon's "More", which deploys deep-learning algorithms. While using a single microphone in background noise, deep-learning has been shown to improve word recognition from 29 to 84 percent which is similar to normal hearing (Zeng, 2017).

AI may also help reduce stigma from wearing HAs (Zeng, 2017). Besides commercial features like direct music streaming, new solutions and benefits like translation and motion detection can make HAs something patients actually want, and not just reluctantly need (Wolfgang, 2018).

Even if ML revolutionises the industry, audiologists will likely still be needed because the process is dependent on real-life data generated by human actions (Townend et al., 2018; Wolfgang, 2018).

Virtual/Artifical Reality

Virtual Reality is adding a new dimension to video games and other visual experiences. As the technology is becoming more advanced, and affordable for the average person, it will open new experiences in the living room. One of the most popular VR games is Beat Saber, a rhythm game where the player uses motion controllers as virtual lightsabers to slash boxes to the rhythm of songs. Jaroslav Beck, its co-developer, figured that it was possible to open the game up for hearing impaired people by using a SUBPAC, a backpack-looking device that transmits the physical sensation of music through haptics and bone conduction.

As Hans Henrik Phillipsen said in his interview, companies like Facebook and their "Reality Labs" are working towards integrating AR in hearing care. One such method is to have an AR consultation with an "avatar" of the audiologist which will make it as lifelike as possible.

Mehra et al. (2020) suggests that AR could help solve the "cocktail-party problem" (problematic listening situations) by providing a system that detects the listener's intent, a system that separates the speakers (digital objects), a system that exploits noise suppresssion (e.g. headphones), and a signal enhancement system that recombines the "digital objects" based on the listeners intent.

An AR platform with AR glasses could provide more microphones and sensors tackling these issues. The system could also be used for data research. Further, the glasses could reduce stigma since eyeglasses generally carry less stigma than HAs and can even be a fashion symbol (Mehra et al. 2020)

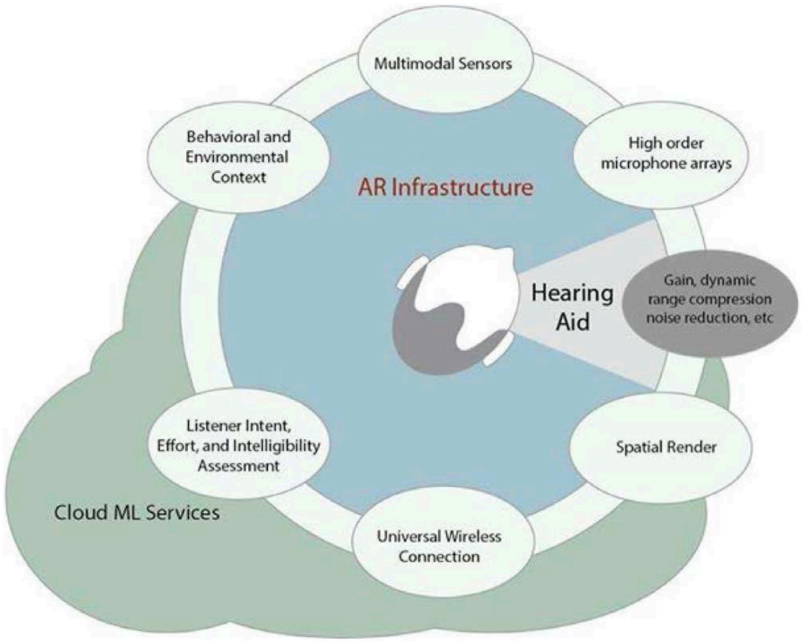


Fig. Suggested AR hearing-enhancing device framework for solving the 'cocktail party problem' (Mehra et al. 2020)

PSAPs and Merging

Personal Sound Amplification Products (PSAPs) existed for decades, but they have mostly been a tool for specific listening situations (Powers & Rogins, 2019).

The MarkeTrak 10 study showed that past and present HA owners were more satisfied with their device than PSAP owners in all categories, except the price. This is expected due to the likely major price variation, but the small difference would suggest that HA owners are overall satisfied with the money they spend. difference in price satisfaction would would suggest that HA owners feel justified in spending the money. It is notable that every single other category is very constant in terms of variation (52-63% for PSAPs and 72-86% for HAs), suggesting that an equal difference in quality, and thereby satisfaction, exists for most of the quality factors. In other words, PSAPs can do more or less the same as HAs, but not as good, for a significantly cheaper price. Given the importance of price, this may make it worthwhile Where the difference between the two products is likely found is in the advanced audio solutions. For example, it is unlikely that PSAPs will offer

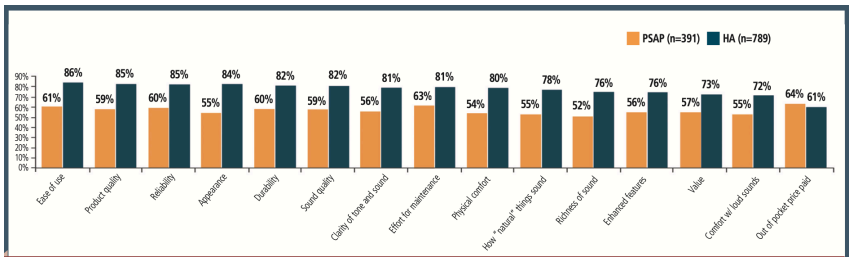


Fig 11. Satisfaction comparison by devices for current and past owners of HAs or PSAPs (Powers & Rosins, 2019)

When PSAP owners were asked how they would identify their device, 42% identified it as an HA, 41% as a PSAP, and 17% were not sure. This suggests that there is a thin between how the two devices are being perceived. This lines gets more blurry when you factor in consumer sound devices, like Apple's AirPods, which are designed for music streaming, but are receiving HA features.

Every person interviewed were in agreement that the merging of HAs and consumer electronics either was on its way or had already happened. Shari Ebert suggested that the merging would be one-way: consumer electronics would take on characteristics from HAs.

8. Discussion

Adoption and barriers

When discussing technology adoption, there are two parameters: the initial purchase and the subsequent use. This project primarily deals with the adoption drivers and barriers for the initial decision and process of purchasing a HA, while also discussing the other parameters. These two are often intertwining. For example, the barrier of denying the need for HAs can both exist before the purchase or when owning a device that isn't being used. On the other hand, the barrier of price value arguably only exists for pre-adopters since it is no longer a concern afterwards.

Another distinction is adoption drivers versus barriers. While both are important and have been discussed, the barriers have been the main focus for this thesis. This is due to HAs being a medical solution where the primary driver will always be their primary

function, amplification a sound, meaning that the drivers are more interesting and relevant. In this case, many of the drivers and barriers also co-exist as 'adoption factors' since they are the simple two ends of the same factor. For example, if "price" or "lack of support" are barriers, then "low price" or "good support" are drivers.

Theory

UTAUT2 was chosen as the primary theory because it is built upon other older theories, assessing their constructs and borrowing as needed. Each UTAUT2 construct is hypothesised to be moderated by some of the factors age, gender and experience. This project discusses these moderators, primarily experience, but do not describe them in greater details. Some studies have not reported any gender or age differences (McCormack & Fortnum, 2013), and a few studies have discussed some differences, but they do not seem to be substantial. A more detailed study could consider them further, but it can be assumed that they are insignificant.

Implants

Hearing implants have a complex spot in the market. On one hand, they are part of the same solution as HAs, but is still a separate business.This thesis has looked into hearing implants to determine how they factor in comparing to general HAs. A related study that aimed to specifically study implants could compare the different brand products against each other.

Market and Localisation

Since this is not market-focused survey, there has not been a focus on the different markets in the world, specifically the United States and Europe where most of the big HA companies are operating and located (only Starkey is American and European brands still sell more devices in the US). In addition, most data and literature regarding market- and user statistics have been about the US, while most interviews have been with people in Denmark. Ultimately, it can be assumed that price cost, which varies between countries, is the only significant location-based adoption barrier, although an advanced comparison between countries or areas (US and Europe particularly) could reveal whether this assumption is true.

9. Conclusions

The hearing aid industry changed drastically with the digital models, and have become increasingly advanced in the next decades. Still, HAs remain underused and there are both technological and user adoption challenges to addess.

If there is one primary adoption barrier, it is denial or the belief that HAs are not necessary. For patients who accept they need HAs, the two biggest factors are denial, cost and stigma. On one hand, free HAs is not necessarily a major driver, but price is a barrier for most people. The stigma, or concern about looks in general, is also a barrier, but one that has improved over the years, as both the looks and features of HAs have advanced. It is especially the size of the HA that matters. The stigma for implantable hearing aids are smaller because the users see them as part of themselves and often have them since childhood. While the adoption rates for cochlear implants are very high for children screened at birth in the west, it remains lower worldwide. Their future success depend on making it natural for people to adopt one as they get older.

Patient-centered care is a viable alternative to the old medicinal model for lifelong hearing impaired patients. Consultation follow-ups, including checkins and support during a trial period, are necessary.

Covid-19 has spurred the need for tele-audiology. It will remain a useful tool on a flexible basis depending on the HTCs and users preferences. Especially for implant patients it is preferred to keep them out of the clinic as much as possible by supporting them remotely. This can be done by making consultations need-based, according to the user, instead of schedule-based which waste time and money.

OTC HAs are still a ‘wildcard’, but show promise for shaking up the market and offer cheaper and more accessible products. They are expected to increase competition and drive down market prices, but at the risk of confusing consumers about what is or is not a real HA. For now, it looks like current HA owners will stick to what they know, while new ones will be open to alternatives. Ultimately, they will likely become a more cheap and accessible option for those with mild hearing loss, but not infringe on the HA market for those users who have severe hearing loss or are willing to pay for better quality.

PSAPs is an alternative to HAs for those with low hearing loss or need for specific listening needs. Despite being cheap and accessible, they cannot compete with HAs in quality. Still, there is a thin line between what users consider to be a true HA or not, and this line may only become smaller as consumer electronics adopt innovations previously reserved for HAs. The technology and consumer audio technology is already merging and will likely continue doing so, and only the future will tell whether these products will merge increasingly and become harder to distinguish. Ultimately, this will increase market competition and give choices to the consumer, but also confuse them about which products are true quality HAs.

References

Bailey, A. (2020a). Resound Hearing Aids. Models, Features, Prices, and Reviews . https://www.hearingtracker.com/hearing-aids/resound (Accessed on 9-3-21).

Bailey, A. (2020b). Phonak Hearing Aids. Models, Features, Prices, and Reviews https://www.hearingtracker.com/hearing-aids/phonak (accessed on 16-3-21).

Bailey, A. (2020c). Oticon Hearing Aids. (Online) Available at:https://www.hearingtracker.com/hearing-aids/oticon (accessed on 15-3-21)

Balling, L. W.; Townend, O. & Switalski, W. 2020. Real-life Hearing Aid Benefit with Widex EVOKE. Hearing Review. (Accessed on 30-03-21).

Bailey, A. (2021). Starkey Hearing Aids

Models, Features, Prices, and Reviews. https://www.hearingtracker.com/hearing-aids/starkey. (Accessed 21-03-09).

Bennett, R.; Laplante-Lévesque, A. & Eikelboom, R. 2019. How Do Hearing Aid Owners Respond to Hearing Aid Problems? American Auditory Society.

Blustein, J. & Weinstein, B. E. 2016. PhD Opening the Market for Lower Cost Hearing Aids: Regulatory Change Can Improve the Health of Older Americans. AJPH, June 2016, Vol 106, No. 6.

Carr, K. 2020. 20Q: Consumer Insights on Hearing Aids, PSAPs, OTC Devices, and More from MarkeTrak 10. Available at AudiologyOnline.com (accessed on 1-4-21)

Chang, V.; Wang, Y. & Wills, G. 2020. Research investigations on the use or non-use of hearing aids in the smart cities. Technological Forecasting & Social Change 153 (2020)

C.K., Gunarathna. Patient Perception of Usage of Hearing Aids and Reasons for Non-compliance in the Adult Population. 2017. Ceylon Journal of Otolaryngology, Volume : 6; Issue1; pp 23-28.

Clark, J. & Swanepoel, D. W. 2014. Technology for hearing loss – as We Know it, and as We Dream it. Disability and Rehabilitation: Assistive Technology.

Convery, E.; Keidser, G. & Hartley, L. 2011. Perception of a Self-Fitting Hearing Aid Among Urban-Dwelling Hearing-Impaired Adults in a Developed Country. Trends in Amplification 15(4)

Copithorne, D. (2020a). Signia Hearing Aids

Models, Features, Prices, and Reviews. https://www.hearingtracker.com/hearing-aids/signia. (Accessed 21-03-10).

Copithorne, D. (2020b). Widex Hearing Aids

Models, Features, Prices, and Reviews. https://www.hearingtracker.com/hearing-aids/widex (accessed 16-3-21).

Copithorne, D. (2021). Costco Hearing Aids. https://www.hearingtracker.com/hearing-aids/costco

Ebrahimi-Madiseh, Azadeh; Eikelboom, Robert H.; Bennett, Rebecca J.; Upson, Gemma S.; Friedland, Peter L.; Swanepoel, De Wet; Psarros, Colleen; Lai, Wai Kong; Atlas, Marcus D. What Influences Decision-Making for Cochlear Implantation in Adults?

Exploring Barriers and Drivers From a Multistakeholder Perspective, Ear and Hearing: November/December 2020 - Volume 41 - Issue 6 - p 1752-1763

Edwards, Brent. 2020. Emerging Technologies, Market Segments, and MarkeTrak 10 Insights in Hearing Health Technology

Einhorn, R. 2017. Hearing Aid Technology for the 21st Century. 28 IEEE PULSE

Ferguson, N.; Wooleey, A. & Munro, K. 2017. The impact of self-efficacy, expectations, and readiness on hearing aid outcomes. International Journal of Audiology, 55:sup3, S34-S41.

Froehlich, M.; Branda, E. & Freels, K. 2019. New Dimensions in Automatic Steering for Hearing Aids: Clinical and Real-world Findings. Available at HearingReview.com (Accessed on 4-4-21).

Goman A. & Lin, F. 2018. Hearing loss in older adults - From epidemiological insights to national initiatives. Hearing Research 369 (2018).

Grewal, R & Irwin, J. 2012. Innovative ways hearing aids can be improved for clinical use A Literature Review. 2012 Scottish Universities Medical Journal.

Gunarathna C.K. 2017. Patient Perception of Usage of Hearing Aids and Reasons for Non-compliance in the Adult Population. Ceylon Journal of Otolaryngology, Vol. 6; Issue1, pp 23-28.

Einhorn, R. (2017). Hearing Aid Technology for the 21st Century. IEEE Pulse 25.

Goman, A. M. & Lin, F. R. 2018. Hearing loss in older adults - From epidemiological insights to national initiatives. Hearing Research 369 (2018) 29-32.

Groth, J. 2020. An innovative RIE with microphone in the ear

lets users “hear with their own ears”. Canadian Audiologist Vol. 7, Issue 5, 2020.

Hampson, R. 2012. Hearing aids. European Geriatric Medicine 3 (2012) 198–200

HHTM. (2020a). 020 Audiology Professional Dispensing Survey.

HHTM. (2020b). Audiologist Survey Report: Fall 2020. Available at: https://hearinghealthmatters.org/hearingnewswatch/2020/audiology-survey-covid-2020/ (accessed on 22-03-21).

HHTM. (2020). Signia Announces Newly Updated Face Mask Mode. https://hearinghealthmatters.org/blog/2020/signia-hearing-aids-face-mask-mode-update/ (accessed on 2021-03-10).

HHTM. 2021. Signia Launches Motion X Hearing Aids; Introduces First Rechargeable Super Power BTE With up to 61 Hours Wear Time. https://hearinghealthmatters.org/blog/2021/signia-motion-x-hearing-aids-rechargeable/

Hoppe & Hesse. (2017). Hearing aids: indications, technology, adaptation, and quality control. GMS Current Topics in Otorhinolaryngology - Head and Neck Surgery 2017, Vol. 16, ISSN 1865-1011

Ingrao, B. 2020. What are OTC (Over the Counter) Hearing Aids and Will They Change the Game? Available at SeniorLiving.org. (Accessed on 1-4-21).

Kim, H. & Barr, D. 2006. Hearing aids: A review of what's new. Otolaryngology–Head and Neck Surgery (2006) 134, 1043-1050

Kover, A. 2020. Feel the groove: Beat Saber and SUBPAC bring VR rhythm game to hearing impaired. https://tech.fb.com/feel-the-groove-beat-saber-and-subpac-bring-vr-rhythm-game-to-hearing-impaired/ (accessed on 21-03-21).

Abby McCormack & Heather Fortnum (2013) Why do people fitted with hearing aids not wear them?, International Journal of Audiology, 52:5, 360-368, DOI:

Mehra, R.; Brimikoin, O.; Robinson, P. & Lunner, T. Potential of Augmented Reality Platforms to Improve Individual Hearing Aids and to Support More Ecologically Valid Research. 2020. Ear & Hearing, Vol. 41, Supplement 1, 140S-146S.

Powers, T. A. & Rogin, C. M. (2019). MarkeTrak 10: Hearing Aids in an Era of Disruption and DTC/OTC Devices. HearingReview.com

Rehman M., Shah, S., Gilani, S., Jamil, M & Amin, F. 2016. An Appraisal of the Advancement of Emerging Technologies in Hearing Aids. Indian Journal of Science and Technology, Vol 9(25).

Ritter CR, Barker BA, Scharp KM (2020) Using attribution theory to explore the reasons adults with hearing loss do not use their hearing aids. PLoS ONE 15(9): e0238468.

Rosenblum, G. 2021. Oticon Focused On Life-Changing Technology. Available at AudiologyOnline.com. (Accessed on 1-4-21).

Sawalich, B. 2021. Starkey: The Future of the Digital Patient. Available at AudiologyOnline.com. Accessed on 1-4-21.

Schmidt, C. (2021). What Are Over-the-Counter Hearing Aids? https://www.health.com/health-reviews/over-the-counter-hearing-aids (accessed 12-03-21).

Shimokura, R. 2018. Hearing Aids. Licensee IntechOpen.

Strom, K. 2020. Hearing Aid Unit Sales Increase by 6.5% in 2019. Available at: https://www.hearingreview.com/inside-hearing/industry-news/hearing-aid-unit-sales-increased-by-6-5-in-2019. Accessed on 30-03-21).

Strom, K. 2021. US Hearing Aid Sales Fall by 18% in 2020. https://www.hearingreview.com/practice-building/marketing/surveys-statistics/hearing-aid-sales-fall-by-18-in-2020 (accessed on 21-03-21).

Tisch M. 2017. Implantable hearing devices. GMS Current Topics in Otorhinolaryngology - Head and Neck Surgery 2017, Vol. 16.

Townend, O.; Nielsen, J. B. & Ramsgaard, J. 2018. Real-life Applications of Machine Learning in Hearing Aids. Hearingreview.com. (Accessed on 30-03-21).

Venkatesh, V.; Morris, M. Davis, G. & Davis, F. 2003. User Acceptance of Information Technology: Toward a Unified View. MIS Quarterly Vol. 27 N.

Venkatesh V., Thong, J. & Xu, X. 2012. Consumer Acceptance and Use of Information Technology: Extending the Unified Theory

of Acceptance and Use of Technology. MIS Quarterly Vol. 36 N

Victory, J. 2021. Hearing loss statistics at a glance. Available at https://www.healthyhearing.com/report/52814-Hearing-loss-statistics-at-a-glance. Accessed on 1-4-21

Wilson, 2017. The cochlear implant and possibilities for narrowing the remaining gaps between prosthetic and normal hearing

Wolfgang, K. 2019. Artificial Intelligence and Machine Learning:

Pushing New Boundaries in Hearing Technology. The Hearing Journal, March 2019.

Yong, M.; Willink, A.; McHahon, C.; McPherson, B.; Nieman, C.; Reed, N. & Link, F. 2019. Access to adults' hearing aids: policies and technologies used in eight countries. Bull World Health Organ 2019;97:699-710.